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# Education Through Visualization: Designing a Year 12 Chemistry Educational Program

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# Education Through Visualization

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## Designing a Year 12 Chemistry Educational Program

An Interactive Qualifying Project Report  
submitted to the Faculty of  
WORCESTER POLYTECHNIC INSTITUTE  
In partial fulfillment of the requirements for the  
Degree of Bachelor of Science  
By:

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Date: 5/3/2012

Report submitted to:  
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## Abstract

In conjunction with the Commonwealth Scientific and Industrial Research Organisation, the team delivered a set of recommendations for the development of a new 3D biomolecule education program targeted towards year 12 chemistry students. To generate these recommendations, the team conducted interviews and surveys of local VCE teachers, reviewed previous VCE Exams, and investigated Visual Molecular Dynamics and its various features. We determined the specific topics of biomolecules that students struggled with and how animations would be able to help. Ultimately, our recommendations will help develop a program that will make complex concepts of biochemistry more accessible to students and educators alike.

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2.2	Methods of Education	Caleb	All
2.2.1	Formal Education	Caleb	All
2.2.2	Informal Education	Caleb	All
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## Abbreviations

CSIRO	Commonwealth Scientific and Industrial Research Organisation
DNA	Deoxyribonucleic Acid
IQP	Interactive Qualifying Project
STEM	Science, Technology, Engineering, and Mathematics
VCAA	Victorian Curriculum and Assessment Authority
VCE	Victorian Certificate of Education
VLSCI	Victorian Life Sciences and Computation Initiative
VMD	Visual Molecular Dynamics
WPI	Worcester Polytechnic Institute

## Executive Summary

Over the last thirty-five years student enrolment in science courses in Australia, and even worldwide, has plummeted. Year 12 students in Australia are opting to take other classes rather than trying to pursue an education in science. Specifically, in recent years, the percentage of students enrolled in the Victorian Certificate of Education (VCE) science courses in Australia has dropped by over half. There are many causes for this decline. The difficulty of the material in many of these classes has been a primary reason for this decline. Due to the complex nature of this material, teachers experience difficulty conveying its intricate concepts. This inaccessibility has also led many students to believe chemistry is not relevant to their lives.

Students and teachers often consider VCE Chemistry as the hardest of the VCE science courses. This course consists begins with introductory chemistry and continues through to subcellular molecules and organic chemistry in year 12. These topics are on such a small scale that they are often hard to visualize and conceptualize. The material for year 12 in particular involves DNA, proteins, and enzyme reactions. These particular concepts are some of the most difficult to visualize, especially on the printed page. Our team interviewed ten educators from various schools across Victoria. Every teacher expressed difficulty conveying the lessons of year 12 chemistry. On top of that, the concepts of DNA and protein structure are sometimes new to the teachers themselves. One teacher stated that she needed to research some curriculum topics for herself, as the material was not covered in her previous university studies. Ultimately, the difficulty of teaching and learning chemistry is not the fault of teachers or students. Our project targeted the difficulties of visualization, and what CSIRO can do to alleviate them.

Because chemistry revolves around the microscopic world, students struggle to conceptualize the material. Unfortunately, many teachers do not have the resources to demonstrate these difficult

concepts. Currently, teachers of other scientific subjects hire CSIRO to provide for their students unique insight into their field. Our team paired with CSIRO to assist in the design of a new educational program targeted at VCE Chemistry, Unit 3 – Area of Study 2.

## Project Goal and Objective

The goal of this project is to provide recommendations for a new CSIRO educational program, addressing the issues of visualization in year 12 chemistry. CSIRO is a world-renowned research and education organization offering informal educational programs presented by professionals from various scientific fields. In order to address the difficult visualization barriers chemistry presents, the program shall deliver three dimensional animations of several sub-cellular structures, such as DNA. These animations will bolster students' understanding of chemistry. Teachers' lessons, while currently sufficient, will be amplified by the visualizations our program will provide. In pursuit of this goal, the team addressed the following research objectives:

- Identify the concepts of VCE Chemistry that are difficult to visualize using standard teaching techniques.
- Determine logistical program requirements.
- Determine the suitability of Visual Molecular Dynamics (VMD) for generating educational animations.

In order to fulfill the above objectives, our team conducted detailed educator interviews and surveys, analyzed previous VCE Chemistry Exams, and investigated VMD and its various features. A matching electronic survey extended the range of our educator pool. These interviews, surveys, and exam analyses guided our program content recommendations. The team analyzed all VCE Chemistry Unit 3 exams since 2008. We reviewed questions relating to biomolecules and examined students' cumulative results, paying particular attention to questions that students consistently answered

incorrectly. These methods culminated in four detailed program recommendations, delivered to CSIRO, for consideration throughout this program's construction.

## Recommendations

### Position in Curriculum

We recommend that CSIRO design this program to as a conclusion to VCE Chemistry, Unit 3 – Area of Study 2. Rather than the program acting as an introduction or intermediate supporting material, a wrap-up style program would allow the animations to incorporate more in depth material. Our educator correspondence indicated that towards the end of the course, students would have already mastered the basic chemistry concepts. As such, our program would not need to review them. This extra time could be spent demonstrating the more complex topics, and how they relate.

Not only would a conclusion-style program allow for more complex content, it also enables the program to present students with practical applications of the entire course's material. Specifically, this program could demonstrate to students the many career opportunities the field of biochemistry has to offer. Many teachers stated that their VCE chemistry students do not see the correlation between the sciences and their lives. Presenting career opportunities would help to make science relevant and intriguing. A simple example of this is Relenza. Relenza, created by CSIRO, is the world's first and most effective anti-flu drug. Production of such a medication requires a thorough understanding of biochemistry. Along with presenting career options, a wrap-up style program is a perfect opportunity to review before the VCE exam, teachers said. By covering VCE-relevant material, the program would help students solidify the difficult concepts presented.



## **Program Content and Narrative**

We suggest that the program cover proteins, protein structures, DNA, and rational drug design. Teacher interviews and VCE exam analysis indicated that these concepts were ideal for this proposed program. These three topics, in conjunction, form a detailed narrative, interconnecting their finer details. For example, according to almost all teachers interviewed, students have difficulty understanding the three dimensional shape of proteins. To combat students' struggles with visualization, we suggest a detailed animation be constructed detailing the various structure levels of proteins, and the forces which create them. These concepts would be expanded upon to describe the operation of DNA, and how protein analysis is used in rational drug design.

## **Molecular Modeling and VMD**

To create the recommended animations, the team carefully evaluated Visual Molecular Dynamics, a free molecular visualization program from the University of Illinois. Working closely with Dr. Mike Kuiper, a computational molecular scientist from the Victorian Life Sciences Computation Initiative (VLSCI) the team assessed VMD's strengths and weaknesses. The team gained a thorough understanding of this program, and evaluated several other example animations. After extensive review, the team determined that there are virtually no limitations with VMD. It is fully capable of representing all of the concepts described above, and provides students with exposure to a professional-grade modeling tool. We have taken note of several useful rendering methods and have included them in all of our content recommendations.

## **Going Beyond Animations**

In order to maximize student engagement and material retention, our team recommends that this program provide other informational activities to compliment these animations. Specifically, we recommend this program include handheld biomolecule models, kinetic activities, and student

worksheets. Multiple interviews, as well as supporting literature, indicate the benefits of supporting material. We suggest the use of physical 3D models of biomolecules in conjunction with animations to enhance the animations' message. To get students up and moving, we suggest using a group physical activity such as having the students arrange themselves as amino acids forming a protein. The activity would pose as a great analogy for protein structure, while remaining easy to understand. A worksheet would give the students an opportunity to apply their skills, helping solidify the knowledge gained from the program. By not using multiple methods to convey information, students will remain focused and absorb more material.

### **Program Practicalities and Metrics**

The team recommends that this program hold 15 to 30 students. We found the average VCE chemistry class has about 18 students. Most schools had one or two chemistry courses. In an effort to keep costs down, many teachers had previously combined their classes for CSIRO programs. Because of this, the program needs to be able to hold up to about 30 students. If the program has too many students, each one would not receive enough attention. However, if the audience were smaller than 15 students, the overall cost per student would be very large.

Ultimately, CSIRO needs to cover its own expenses. The team recommends that CSIRO should charge schools 20 to 30 dollars per student for this program. Most teachers and schools are fine with paying this amount for an educational program. Many CSIRO programs currently have similar costs and other school excursions do as well. In the past CSIRO has worked with RMIT to bring educational programs to underprivileged schools that normally could not afford them. RMIT paid for the programs, and the schools received an educational experience that they would normally not have been able to receive. Because of this, the team recommended that CSIRO continue to arrange sponsored program

sessions as much as possible. This way many schools will be able to afford the program normally but schools with large amounts of underprivileged students will not miss this opportunity.

# 1 Introduction

The subjects of science, technology, engineering, and mathematics (STEM) are the basis for the technological advancement of our modern society. Many industries require and need more STEM educated individuals. However, there is a general decline in individuals pursuing STEM education. On a global scale, only 60% of freshmen majoring in STEM fields of study are able to complete their degree requirements (Gregson, R. 2007). According to a 2003 study, almost all American universities have seen a decline in STEM areas of study since 1970 (Peterson, 2003). A similar trend can be seen in British high schools as well; currently only about 15 % of British upperclassmen are enrolled in math and science classes (Osbourne, J., Simon, S., & Collins, S. 2003).

The educational trend in Australia is no different. In the past three decades, student interest in STEM fields has sharply declined. For example, year 12 enrollment has dropped by more than half in subjects such as biology, physics, and chemistry (Ainley 2008). The current national curriculum for Australia only mandates science and mathematics education up through year 10. Years 11 and 12 are governed by the Victorian Certificate of Education (VCE). During these years, students select the courses they wish to take, rather than following a set curriculum. At the end of these two years, students must pass state written standardized exams in their courses, in hopes of obtaining their certificate of education. Educators have a large amount of material to teach their students to prepare them for the exams. Time is often very limited when trying to cover all of the material. Teachers are forced to move at a very fast pace, and use less creative styles of teaching that favor efficiency. We found from interviewing VCE teachers that lectures are used as the primary method of teaching. However, most students tend to be less receptive to and less engaged by lectures (Goodrum 2001).

One method teachers use to keep their students engaged is to incorporate multimedia and other new technologies into the classroom. Experiments, projection systems, and lab equipment all provide students with different views of the same material. This provides valuable insight into the topics. However, due to various cost constraints, it is impractical for most schools to provide specialized equipment for educational purposes. Given the limited ability of school-based science education programs to engage students, teachers often turn to the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for help. Although better known for its cutting-edge scientific research, CSIRO has a dedicated education division that creates unique and engaging programs for students at school or at one of several CSIRO locations. For example, the program *Materials and Structures* allows VCE physics students to use high tech equipment to help further explain like the tensile strength of heat treated steel. Students would not normally have access to CSIRO's high tech equipment to be able to heat treat steel, and measure the large tensile loads up to it breaking. For reasons like this, CSIRO's programs are highly regarded for their "curriculum relevance, program price, and student engagement" (Carney, K. et al. 2011).

CSIRO offers many educational programs for students of all ages and in many areas of study. However, CSIRO currently does not have any programs which cover the specific biochemistry concepts of proteins, DNA, and organic chemical pathways. These rather complex topics have been difficult for students to grasp when presented with solely textual and lecture explanation. Studies suggest that students exposed to a variety of representations fair better with this complex material (Uitto, Anna, et al. 2006). Interviews with local year 12 VCE Chemistry teachers concur with these studies. They also indicated that teachers have difficulty providing meaningful visualizations due to lack of resources available to them. According to one VCE Chemistry teacher we interviewed, "students often have

trouble conceptualizing two dimensional images found in their textbooks, and realizing that these objects exist in three dimensions.” This is where our program comes into play.

The team has supplied recommendations to CSIRO for constructing the foundations for a new 3D biomolecule education program targeted at year 12 students. The program will cover the complex features of organic chemical pathways. To ensure the effectiveness of this program, the team conducted several interviews with local educators. These interviews solicited information about program parameters and subject matter. We designed these interviews to determine which areas teachers are having difficulty with, and what kind of visualizations they would find useful. The team, with the help of Mike Kuiper of the Victorian Life Sciences Computation Initiative (VLSCI), designed a storyboard for the production interactive animations to be incorporated into the program. These storyboards will be given to CSIRO along with other recommendations for the program. This program will help solidify students’ understandings of complex protein activity, and biochemistry as a whole.

## **2 Background Research**

### **2.1 STEM Education**

#### **2.1.1 Importance of teaching STEM in high school**

The world's demand continues to grow for science, technology, engineering, and mathematics educated individuals. These core subjects are important for the development and advancement of our society as a whole. It is scientists that develop new medicines, and engineers that design our modes of transportation. STEM subjects are crucial for the technologies that our society relies on. For instance, there are still many diseases without a real cure, like HIV. It will require a scientist to discover many of these cures.

#### **2.1.2 Global interest in STEM**

To improve the national infrastructure, and promote research growth, society needs a continuous influx of scientists and engineers. In order for this to happen, there must be an equally constant supply of students being educated in science and technology in high school (ASTEC 1998). Those students who receive instruction in science gain a better appreciation for it. Therefore, they are more likely to enter into a related field for a career.

The unfortunate truth is that there are far fewer individuals pursuing STEM field careers than there should be and used to be. A study conducted of Indian universities showed physics and chemistry courses had the highest dropout rates when compared to other majors (Garg, K. C., & Gupta, B. M. 2003). However, the study showed that more and more students are attempting to receive degrees in economics and accounting. In an attempt to remedy the lack of interest in science and technology fields, the Indian government has developed scholarship programs specific to students in these fields.

Similarly, the British department for education has witnessed a continual decline in science and mathematics interest. During 1980, about 30 percent of high school students, age 16 and up were enrolled in science and math courses. The percentage of high school students enrolled in math and science courses dropped to 16.6%, only a mere thirteen years later. Specifically, from the year 1990 to 2000, the number of students enrolled in physics classes in high school decreased from about 45,000, to 30,000. The same study showed that of the students enrolled in science classes, less than half of them deem the subjects interesting. On top of that, about half of the students enrolled believe that science classes are too hard to understand (Osbourne, J., Simon, S., & Collins, S. 2003).

In a study conducted by teachers in Australia, the teachers found that the primary motivation for a student choosing a class is its level of difficulty. Most students believe science and mathematics to be too difficult. If students perceive subjects to be too hard, or irrelevant to their lives, they opt out of taking them (Moodie, G. 2001). This repulsion of difficult courses is part of the reason that students, when given the choice, are less often choosing STEM courses.

### **2.1.3 Australian Decline in STEM education**

Australia suffers from the same waning in STEM education that many other countries are experiencing. Across the country, teachers are finding it increasingly difficult to fill science courses. Fewer high school students are enrolling in science classes every year. From the years 1978 to 2002, participation in year twelve chemistry, biology, and physics courses decreased by over 50% (Ainley, J., Kos, J. & Nicholas, M. 2008). Figure 1 shows this decline in students taking science classes from 1976 to 2007.



One reason for this visible decline is the dramatic switch in education styles from elementary years, to secondary education. Primary school courses use an

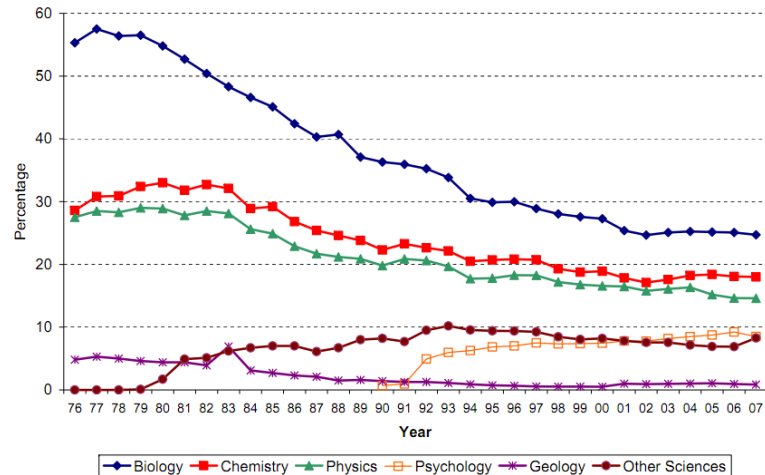


Figure 1- Year 12 science participation as a percentage of the Year 12 cohort

interactive, “hands on” approach. Teachers utilize various interactive methods to hold the younger students’ interests. Science classes in the upper years, however, are predominantly taught with a direct lecture approach. The subject material presented in these higher-level classes is typically complex, and difficult to visualize. This is a large contributing factor to its decline in interest and registration in high school upperclassmen (Goodrum 2001).

The students enrolled in Victorian Certificate of Education (VCE) science courses report that the material from these classes is more difficult to relate to than many other elective courses. According to the article “Marketing Australian Tertiary Education”, subject relevance is one of the most significant factors students consider when selecting courses (Moodie, G. 2001). Students select courses that they think are relevant to their personal lives and society. Since students place such a high importance on relevance of coursework to their lives it is important to show how relevant science is to them when developing a curriculum.

The Victorian Certificate of Education regulates the studies of year 11 and 12 students of the state of Victoria. During these two years, students select subjects they wish to study. Each subject is broken down into four units each. A semester of schooling covers one unit. Each unit is broken down

into specific areas of study. These units and areas of studies are mandated by the Victorian Curriculum Assessment Association. Students wishing to continue their education into Universities must complete and pass General Achievement Tests. Completing these exams fulfill students' requirements for their VCE courses (VCAA 2012).

### ***2.1.3.1 Decline in Australian Universities***

Over the last 30 years, Australia has seen an increase in general studies university enrollments. While general enrollment has increased, science enrollment has decreased. Some believe the primary cause of low science enrollment is the declining interest of the year twelve students. Professors state that classes that appear relevant to students' lives are the often boast large class sizes (Moodie, G. 2001). This is as opposed to classes that are abstract and theoretical, like mathematics and sciences. The low enrollments these classes have caused universities to downsize the faculty teaching these subjects. A dire example of this is that "Between 1996 and 2006 around a third of academic positions in university mathematical sciences departments had been lost, with many universities now employing fewer than 10 mathematics staff" (Thomas, J., Muchatuta, M., & Wood, L. 2009).

## **2.2 Methods of Education**

Overall, when deciphering the low enrollments of math and science courses in both high schools and universities, a reoccurring theme appeared. Students respond well to certain methods of education. Techniques for educating students vary from rote memorization in the classroom to hands on experience during a class excursion. Even when it comes to science education specifically, the methods are myriad. Studies show that students can benefit from both formal classroom education and informal education, which takes place outside of the classroom. Additionally, the way children are taught affects how they react to the subject, along with the amount of retained knowledge.

### 2.2.1 Formal Education

Formal education is the primary method of education used in most public and private schools. It includes both in-class lectures and homework. Sallee and Rigler's 2008 investigation shows that how homework is used as a teaching tool varies and is not always as efficient as one might hope (Sallee, Rigler, 2008). Students comply because they are under constant pressure to get good grades. They are also expected to learn a large amount of information in a very short time. As such, it is often easier for students to simply memorize facts, rather than build the complex understanding that the subject matter requires. While formal education is easier to regulate and systematize across schools, there is a need for students to have breaks from routine and learn in ways that are more experiential and less rote memorization.

### 2.2.2 Informal Education

Informal education is the complement of formal education, and includes field trips, group projects, and other tangents to classroom lectures. As seen in Anna Uitto's 2006 report, out-of-school programs provide more interactive educational experiences than in school lectures. These experiential lessons help foster a real understanding in the students. Self-efficacy, or confidence in one's ability to complete a task, is a strong indicator in whether someone is willing to pursue a subject (Uitto, 2006). By allowing a student to complete a project or see direct results, which are often a part of informal education, a student's confidence can be greatly increased (DiLisi 2011). As shown in Figure 6 below, by having students get direct experience working with STEM professionals they have an increased interest in pursuing those fields.

Project WISE was a case study aimed at presenting participants with real life scenarios and problems in order to educate them about different sciences. These problems required the use of science and mathematics to solve. Before participating in the *Project WISE: Working in Informal Science*

*Education* there were not any students considering careers in geology or math education. However, after the program, there was an interest from the students and in general the appeal of working in a STEM field increased. This can easily be seen in figure 6. The red bars on the graph show the percentage of students that expressed interest in a subject as a career prior to participating in the program. The blue bars represent the percentage of students interested in a subject after completing the program. In general, the percentages of students interested in STEM careers increased after the program.

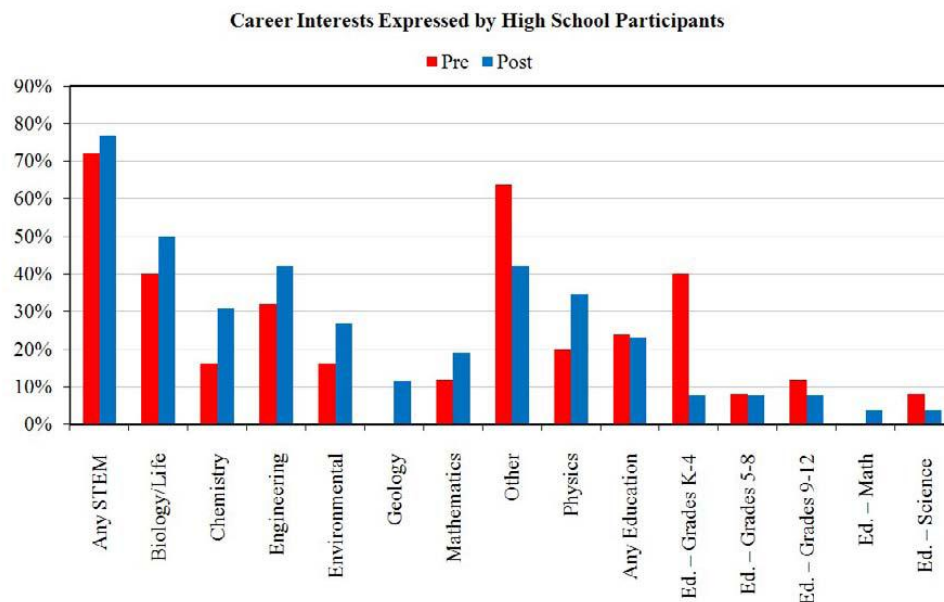


Figure 2 - High school students' career interest.

### 2.2.3 Benefits of having both educational methods

The interest that can be generated by informal education can lead students to seek out ways to learn more in a formal educational setting. The number of students taking science classes will increase if the desire to learn about science increases. Ideally, informal education, such as what CSIRO provides, will fit into the planned formal education that a student would also receive according to the curriculum, such as the VCE. Just as properly proportioned homework can create teaching moments when a teacher

is not there, a well-planned informal education experience can do the same. There are very few educators who would remove homework from schools; informal education experiences should be treated as equally important in helping students learn.

#### **2.2.4 Commonwealth Scientific and Industrial Research Organization**

There are very few informal education resources Australia. CSIRO is one of the leaders in this. Since its formation in 1982, CSIRO Education has provided Australia with a number of fantastic educators and educational programs. The Commonwealth Science and Industrial Research Organisation, CSIRO, is Australia's national science institution. It employs over 6000 staff and has over 50 sites across the country (csiro.au). CSIRO is heavily involved with the public schools and education, and is one of only a few educational excursion providers that have programs specifically for the VCE curriculum. As well as performing some teacher development, CSIRO has a wide range educational programs and school assemblies for kids of all ages. For example, CarbonKids was a 2011 program centered on environmental sustainability and carbon emissions. The program visited over 170 schools over Australia teaching the practices of recycling and environmental protection. CSIRO makes it very easy for to for schools to experience these supplemental educational programs. School districts hire CSIRO to bring programs to the sites of the schools.

CSIRO offers a number of programs for all different aged audiences. Some of the most hired programs they offer are their VCE programs. VCE teachers like to hire CSIRO for many reasons. These programs provide students with the chance use expensive equipment to complete practical experiments they normally would not have the resources to do. The VCE programs also provide students with a comprehensive overview of the course material. The programs act as a great review for students when preparing for the VCE exams. At the end of the VCE years, the students must complete comprehensive exams in all of their courses.

## 2.3 Biochemistry

The concepts behind modern biochemistry covered in VCE chemistry have become increasingly complex over the past decades. Since their classification in 1953 by J. D. Watson and F. H. C. Crick, the field has rapidly expanded (Watson, J. D. 1953). Teachers are now passing along this new knowledge to their students. However, the motion and behavior of sub-cellular components can be very difficult to visualize. For example, concepts like the shape and formation of DNA and the causes of protein folding require a new perspective. This perspective can be very difficult to provide through standard lecture and note taking methods. Understanding these concepts helps illustrate the complexities these topics, as well as exposing the difficulties imposed on both students and educators.

### 2.3.1 Proteins

Proteins are a widely varying class of sub-cellular components, and are the most basic functional component of all living cells. They provide numerous different functions for the body, and can be found underlying almost every action of the body. A protein is simply just a very long chain of amino acids. There are 20 different amino acids, all containing varying characteristics. For example, some are hydrophobic; some are highly polarized, while others remain non-polar. These acids bond with a long polypeptide chain, forming a backbone to the protein. Ultimately, it is these complexities that are in part reason to why it is difficult to learn about protein functions and structures (Alberts et al 2004).

## 2.4 Visuals in Education

There are many teaching methods for trying to convey the complexities of chemistry. Currently, visuals have shown to be some of the best tool when learning chemistry. In the year 2000, the University of Michigan piloted a graphic based chemistry curriculum. The software, eChem, helps students visualize the structures of molecules. Over the course of 6 weeks, students at local high schools used eChem to complement the material learned from traditional lecture style teachings. Overall, the students that

used this visual aide developed a deeper understanding of the material. They were able to draw relationships between the visualizations, and the lecture material. The study concluded that computer aided visuals drastically increase students' abilities to mentally conceptualize the material, and learn it better (Wu, H. K., J. S. Krajcik, and E. Soloway, 2001).

Although two-dimensional computer visualizations help when teaching complex material, three-dimensional visualizations are able to contain much more information in one image or video. The main issue, in terms of educational, is the lack of resources and content. A majority of school do not have three dimensional projectors, or animations to use with these projectors in a classroom setting. However, this is where CSIRO comes in. CSIRO has the resources to bring a 3D projector to schools. Our team set out to determine what type of content teachers would want out of a biochemistry educational program.

### 3 Methodology

*“Our project is intended to assist CSIRO in creating the foundations for an animation driven, 3D biomolecule education program targeted at year 12 VCE Chemistry students.”*

The team designed the foundations for a 3D biomolecule educational program that not only engages students, but also helps them understand the complex subject matter in their VCE Chemistry course. We did so by first identifying three key objectives to focus our research.

- Identify the concepts of VCE Chemistry (Unit 3- Area of Study 2) that are difficult to visualize using standard teaching techniques.
- Determine the suitability of Visual Molecular Dynamics (VMD) for generating educational animations.
- Determine logistical program requirements.

Upon completing the above objectives, the team was prepared to fulfill their primary deliverable of generating recommendations for how a new program should look and operate. These recommendations are supplemented with example storyboards and animations. Figure 3 shows how these objectives and our various constraints relate.

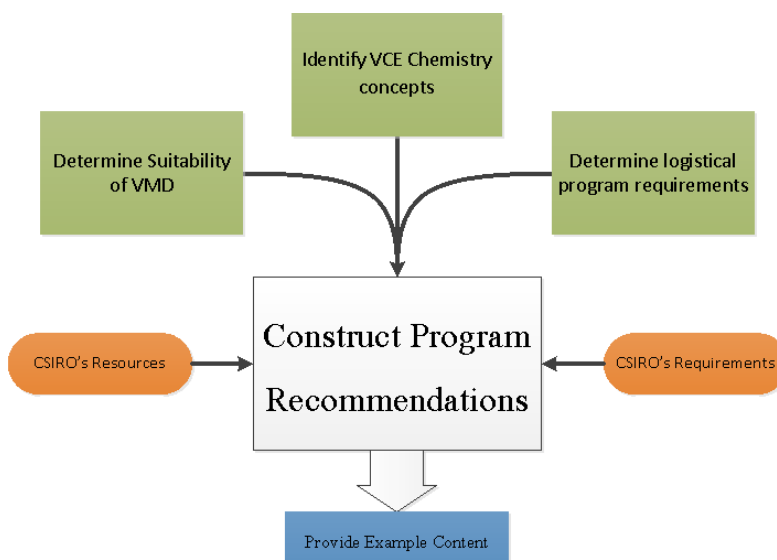


Figure 3 - Project Flowchart



### **3.1 Identifying key scientific concepts to communicate to students**

The primary goal of CSIRO's proposed program is to help teachers and students understand some of the more complicated aspects of biochemistry. Before our team made any storyboards, the team identified all of the scientific concepts that the program will include. The team identified these concepts by examining the supporting VCE documentation and conducting educator interviews in order to see exactly where students are struggling, what areas teachers would like support in, and how best to overlap those two criteria. These critical viewpoints provided the team with a substantial knowledge base to communicate to CSIRO.

#### **3.1.1 Educator Interviews**

From early on we recognized the importance of teacher feedback in creating this program. We targeted year 12 VCE chemistry teachers because they have firsthand experience with how to teach students the material, as well as which topics the students find difficult. Since we aimed to have our program support current teachers, it would have been a serious oversight not to consult them. Despite the fact that Victorian schools have a two-week holiday around Easter, we were able to interview nine VCE Chemistry teachers and a former teacher working with CSIRO. In addition to interviews, we sent out a survey to educators in Victoria. This survey was also included in a newsletter sent to a wide variety of VCE chemistry educators, and mirrored the questions target in our interviews. The survey received 12 responses from VCE chemistry teachers. The entire electronic survey has been included in Appendix C. The number of respondents for the survey was not large enough for strong statistical analysis, and was, instead, approached in a more qualitative manner, as our project goals do not require a numerical analysis. Our team was more interested in obtaining detailed open-ended responses, so that we might glean information about the educational situation at hand. While 22 responses in total might not seem

that large, we were able to gather a good understanding of these different VCE chemistry teachers' curriculums. These viewpoints enabled the team to generate thorough and helpful recommendations.

We were able to interview teachers working for the three main types of schools, government, independent, and catholic. These schools ranged from poor to rich, single gender to mixed, and religious to secular. While the number of interviews may be lower than expected, our dataset encompassed all three school types. The variety was ideal for showing us how teachers are able to do their job when they have near unlimited resources or almost nothing. CSIRO's program will be marketed to VCE chemistry courses, which all are required to cover similar content. Our team managed to interview a good variety of school types, removing any potential bias that can come from only obtaining data from a particular type of school. For instance, responses from an affluent, all girls, Catholic college, would widely vary from a public school. This ensured that our recommendations would help generate a program that was applicable to schools all around Victoria.

Educator interviews were a primary source of information for this project. CSIRO maintains a close relationship with its client base, and wished to tailor this program to these individuals' needs. CSIRO was under the impression that many teachers had problems and difficulties teaching this particular subject. They wanted to know specifically what students struggled with to design a program around. If the interviewed teachers reported not actually having any troubles with the area of study, the team would have recommended that the program idea be discarded.

CSIRO's database of previous program bookings became a primary source for interview subjects. Educators who taught VCE Chemistry and had booked a CSIRO chemistry program since January 2010 were first contacted. The team selected these teachers also for their familiarity with CSIRO educational programs. Teachers who have booked other CSIRO programs such as Polymers and Nanoscience are familiar with how the programs are run, what sort of content they can cover, and more specific metrics

such as program duration and cost. In general, these teachers understood how CSIRO operated with classroom excursions, making them more apt to provide a clear ideas of what they would like to see in a program. These teachers were our initial focus because we realized they could efficiently supply us with a lot of information.

To gain further responses we expanded to schools in the Melbourne area. These educator interviews equally provided insight into the effectiveness of current teaching methods. They identified areas in which students struggle to conceptualize the material, and where our visualizations will be most helpful. Teachers also identified the methods they were using to teach biochemistry at that time. By understanding what teachers were already doing, we could then recommend that the program utilize proteins or other more specific concepts that the students were already familiar with to reaffirm the teacher's previous lessons.

We maintained a casual atmosphere with our interviews which led to teachers being quite forthcoming about their teaching methods. We were cautious of leading questions and designed the questions to elicit discussion, rather than one or two word answers. This led to obtaining additional information that we could not have predicted. For example, one teacher was kind enough to give us a copy of the PowerPoint presentation she uses to teach. In order to maintain a comfortable and open interview session, the team worked from a set of interview guidelines, rather than a standardized script. The team guided the less formal conversations through a series questions, hoping to elicit as much information as possible. These questions fell into one of two main categories, Program Metrics or Education Techniques.

The education technique questions aimed to capture the effectiveness of current teaching efforts. Because the program we are creating recommendations for will be supplementing current teacher curricula we sought to find out more of what gaps exist. The team designed the open-ended

questions to spark discussion of what gaps exist, what the possible reasons may be, and what could be done to help students get past any holes in their knowledge. We worked with the teacher to gain a thorough understanding of their individual curriculum layout, thus allowing us to obtain a better idea of where CSIRO's new program could fit.

The first question we asked during every interview was about what tools the teacher used to teach students about DNA, proteins, and enzyme actions. The team asked this question to determine what types of visuals students are already being subjected to. This was partially to make sure that the program would not use duplicate visuals or animations that teachers were already using. However, this question was also used to find any good resources to use as reference for generating recommendations for animations. Determining the tools teachers used also lent insight into possible reasons for why students had difficulty with certain sections

The team also inquired about if teachers had difficulty teaching any specific sections from this area of study. On top of that, the team also asked what specifically was difficult about it. This question directly solicited the information for which a lot of the program topic recommendations were based on. The teachers had the best idea of where students could use supplemental education. If multiple teachers concurred upon a certain topic, it was included as a topic recommendation. This question was often very direct and to the point, gathering very useful information.

One question that was much less direct inquired about how strong of a grasp students had on the material at the VCE exam. CSIRO education often stresses that its educational programs are geared to vastly improve the general knowledge of students. There was a fear that many students simply memorized the material in preparation for the test instead of actually mastering it. CSIRO wanted to gear the program around helping students master the information. This question tried to solicit areas where teachers believed students may have just memorized test answers, instead of thoroughly learning

the material. It was often a less direct question, and teacher bias might have gotten in the way of insightful responses.

The last question the team asked about program content inquired about specific proteins or enzymes the teachers already used, and whether or not they wanted help in illustrating these concepts. In other programs, CSIRO used examples common to a lot of teachers' practices. This was to reaffirm what the teachers had already taught in class. This question also gave the team a good place to start when determining program content. It quite directly asked teachers what they would like to see in a 3D visualization program.

One very important education question asked during the interviews, focused on how our program would align with teachers' curriculums chronologically. The timing for the program is both a practical matter as well as an educational issue. For instance, some teachers wanted to use the program as introductory material, whereas others preferred a conclusion to their course. This key bit of logistical information had a huge impact on our program recommendations. A program used primarily at the beginning of a course would have to include a significant amount of introductory material. The students would need to understand several basic concepts before continuing on to the complex 3D model demonstrations. A wrap-up presentation, however, would allow for much more information depth. The presenter could spend less time reviewing, and more time presenting our new material. In our interviews, the team asked where the teachers imagined using such a program, and what kind of knowledge the students will have by then.

The knowledge students come into a program with can drastically change how the program goes. From observations of CSIRO programs we saw firsthand how a program can lose effect if students are not properly prepared for it as well as if a program expects too much of students. In our interviews with teachers we discussed not only when in the school year they think this program should be but what

type of knowledge students would have at that time. This knowledge let us determine exactly how in-depth the program can go. If teachers prefer to have the program at the beginning of the course then it would serve as a way to inspire curiosity in students as well as give them images to remember when they learn the material later in the term with their teacher. If teachers prefer to have the program at the end of the course then more complex topics can be covered such as rational drug design or even career opportunities in biochemistry. Any questions students may have during their studies may also be clarified by the animations. If teachers prefer to have the program in the middle of the term then a balance of breadth and depth would be struck which both help students absorb what they have been learning and motivate them for the rest of the term. No matter what the position in the term has a significant effect on the complexity of the animations and what material will be covered. These questions were the main focus of program content; however a full copy of our interview guidelines has been included in Appendix B.

**5. Please rate how strongly you agree with the following statements.**

**By the end of this unit...**

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	N/A
Most of my students have a very firm grasp of the subject material	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Most of my students understand the structure and functionality of proteins and DNA	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Most of my students have not simply memorized definitions, but understand the material at a fundamental level	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Most of my students are able to apply the skills they have learned in other areas	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Most of my students have learned material beyond what is required for the VCE Exam	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure 4 - Agreement Rating survey sample

Along with educator interviews, the team created a survey to distribute to educators as well. The survey we constructed targeted data similar to the in-person interviews, but only delivered through a different medium. It was used as supporting evidence in conjunction with the interviews. This data was used a few more quantitative questions as opposed to the interview data. Some of our recommendations, such as cost, require a more quantitative result. Our survey excelled at providing that type of information as well as giving more measurable backing to our interview questions as shown in Figure 4. By then comparing responses from interviews and the survey we can ensure that there is no bias from how we gathered the data, or at least account for it if there appears to be bias.

The survey initially was sent to VCE teachers who were too far away to be interviewed personally because of transportation limitations and later sent to any teachers who were unresponsive to interview requests. A copy of this electronic questionnaire has been included in Appendix C. The Program Metric questions did not change between the personal and electronic versions. However, the education-techniques questions did require a format change. The team generated questions where a teacher would have to select how well they agreed with the statement. An example of this was how we asked if the students had a firm grasp of the material before the VCE exam.

One benefit of using the survey was that it supplied more quantitative evidence as opposed to interviews. As shown in Figure 4 teachers have directed responses in the survey and therefore solicited more direct responses. The survey questions were geared to generate simple responses in a method that would be awkward and impersonal to ask at an in person interview. These responses were also easier for us to analyze that information than the interviews. The downside of surveys not being as full-bodied as the interviews was balanced by this directness that teachers were forced to have. A concise opinion can be compared between educators and supply a different style of data than we received from the interviews. The surveys were also expected to have a higher response rate. This low response rate

led to us relying on other sources of information more than initially expected. The documentation provided by the Victorian Curriculum and Assessment Authority proved to be quite valuable when combined with information gathered directly from educators.

### 3.1.2 Examining Supporting VCE Documentation

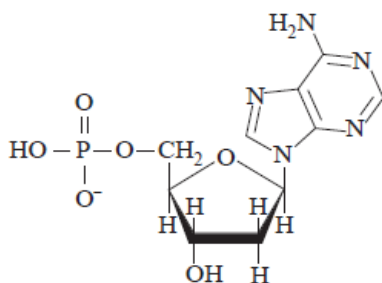
As described in the previous chapter, the Victorian Certificate of Education (VCE) standardizes testing for Victorian students in years 11 and 12. The Victorian Curriculum and Assessment Authority (VCAA) provides several supporting documents for the VCE program, including previous exam papers and assessment reports. The team closely examined these documents, as many VCE teachers “teach to the test” because of their demanding time constraints. Specifically, the team identified all of the questions related to biomolecules, including DNA and proteins. From there, we reviewed the corresponding assessment reports looking for questions and topics students performed poorly on. By looking for questions that students performed poorly on, the team was able to determine areas where students could have benefited from supplemental education. If all of the students answered a question on DNA transcription correctly, the team would recommend against including that topic into the program. These assessment reports showed statistics for student responses, and provided possible explanations as to why students might have answered a question incorrectly. By analyzing these reports we were able to see what topics students typically performed well in and where students need help with a precision not available from interviews or surveys. We compiled the information gathered from this exam analysis and compared that information to the results from the interviews and surveys.

The VCAA comments included on the exam assessment reports show why they believed students did not determine the correct response to a question further indicated the knowledge gaps that CSIRO’s new program needs to fill. A sample question with assessment and comments is shown in Figure 5, along with a full exam assessment report included in Appendix D. We used the comments on



questions as specific directions for ways that our program can help students. For instance, Figure 5 shows that students have some difficulty with terminology, which we discuss further in our findings. As can be seen in this particular example, 76% of students got 3 marks or points, which is full credit. Some questions on the assessment reports also supply common wrong answers that students gave. These wrong answers are used to confirm the suggestions that the assessment reports give as to what students did not understand. We compared what the assessment reports believe students do not understand with what teachers believed students struggled with. The VCE exam results are from every VCE chemistry student in the state of Victoria, and combined well with what teachers report to us which. The impersonality of the VCE Assessment Reports prevents any anecdotal information that can happen with interview. The team originally worried that teachers might overstate their class's understanding of the information. The exam assessments provided clear and understandable responses lacking bias. The exams also helped to provide us with a better idea of what topics teachers are required to teach.

Four different monomers known as nucleotides undergo condensation reactions to form a strand of DNA. The structure of one such nucleotide is shown below.



b. Name the reactants that have combined in condensation reactions to form this nucleotide.

6b.

Marks	0	1	2	3	Average
%	8	4	13	76	2.6

All of:

- phosphoric acid/phosphate
- deoxyribose
- adenine.

Students who did not gain full marks on this question often did not correctly name all the reactants. The general groups 'sugar' and 'nitrogen base' were given instead of the specific compounds 'deoxyribose' and 'adenine'.

Figure 5 – Open Response Question Number 6 and assessment.

76% of students got full credit by answering with all three reactants: "phosphoric acid/phosphate, deoxyribose, and adenine".

## 3.2 Identifying constraints imposed by teachers' curriculums

As with every school curriculum, there are certain constraints imposed on third-party programs, such as class period length, school budget, and curriculum scheduling. A program must be able to also satisfy these often inflexible factors as well as deliver excellent content. In order to create a successful program, we first needed to identify these various criteria, and then design our program accordingly. Virtually every teacher interviewed agreed that class time in a VCE course is very valuable due to the amount of information teachers must go through to prepare students for the VCE exam. The educator needs to know that this program will add significant value to their coursework before they would consider including it in their already packed schedules.

### 3.2.1 Program Practicalities

As mentioned previously, our interviews contained several program-metrics questions. These questions were very helpful in identifying curriculum restraints, and were easy to deliver alongside the education-technique questions. Program-metrics questions targeted topics such as class size, program duration and price per student. These questions were very straightforward, some even answered with just a simple numerical answer. A few of these questions are listed below:

- How many students should we expect to accommodate?
- What is your desired program length?
- What is a reasonable price to pay for this program (per student)?

Determining class size helped with program development. The program needed to be able to be available, and taught at several locations, including schools of varying sizes and CSIRO's teaching centers. As a result, an average class size of VCE year 12 chemistry classes needed to be determined. During each educator interview, our team inquired about the average class size for this course. Even though class sizes varied from year to year, determining an average size helped in creating a better-tailored program. Statistics on class size were not specifically found for VCE courses so we elected to include this question in our interviews instead. This provided answers that expanded on course organization. For example, one teacher said that she would likely book one session, but invite two separate classes to attend.

The duration of an average VCE chemistry year 12 class also lent helpful insight to program development. The program needed to fit in an average class period. Since class time is very valuable to year 12 teachers, we wanted to make sure that the program would fit into as many schedules as possible. For example, some teachers wished to fit the program in to their usual 70-minute class period, while others preferred to use their double block, which might be as much as 90 minutes. Our team inquired about the average period size during the interviews and with the survey.

### 3.3 Identify the features and limitations of Visual Molecular Dynamics

#### (VMD)

As with any tool, it is important to understand how to use it appropriately. The field of 3D animation is no different. Before our team began the actual media generation, we identified the strengths and weaknesses of the biomolecule visualization software we would be using, Visual Molecular Dynamics (VMD). In order to create effective animations and storyboards, the team needed to know what the limitations of VMD were. The team didn't want to generate a storyboard for visuals for something that simply couldn't be animated. We needed to know if it was possible at all to make our animation ideas a reality. After determining those limitations, appropriate storyboarding could commence.

The first step in learning about VMD was completing the online tutorials about it. No one from our team had any previous knowledge of how to use this animation program. When it came down to it, we had to learn exactly what the program allowed us to do or didn't let us do. Our primary source of information about VMD was Dr. Mike Kuiper, an animation specialist with the Victorian Life Sciences Computation Initiative (VLSCI), which is a partner with CSIRO. Informal discussions with Kuiper provided insight into the operation of VMD, including its strengths and weaknesses. He has created dozens of biomolecule animations in the past, and will be working closely with CSIRO to generate animations during the actual creation of the new program. We discussed, at length, the features and capabilities of VMD, hoping to gain direction for our recommendations and storyboards.

Features of VMD included methods of how to represent certain proteins or DNA. The team needed to decide the best way to display these two things, so students would be able to understand the concepts being portrayed. For instance, proteins could be displayed with traditional ball and stick

methods, or a more modern ribbon style. Other specific features included the ability to rotate and magnify images, simulate molecular forces, and render animations

Any limitations of VMD were also discussed with Kuiper. The team discussed how the limitations affect his work, and how he manages them. Since no one in the team had any prior knowledge to using VMD, the team needed to determine what we could and couldn't do. We weren't sure if we could have the molecule move or bend in certain ways. Ultimately, we needed to learn the basics of the program. By understanding Kuiper uses VMD to create his own personal animations, the team was able to give more useful and pertinent storyboards and recommendations.

### **3.4 Construct Final Deliverables**

All of the research objectives provided key information for the program's design. The content presented to the students must be both well organized and relevant to their studies, as teachers have a very tight schedule and will need to clearly see the educational value this program brings. Our final deliverable is a set of recommendations and supporting material to be delivered to Caitlin Lewis and Chris Krishna-Pillay of CSIRO Education. The recommendations will consist of suggestions for animation storyboards, program notes and guidelines. These storyboards provide detailed, step-by-step directions to guide the animations. The animations are designed to tell complete stories of certain proteins, including their structure, assembly and function. DNA will be treated in a similar fashion. The ability to zoom in and out as well as rotate the image will allow students to see exactly what is happening to the DNA.

The program notes are a private assistive document accompanying all of CSIRO's programs. These notes remind the presenter of the key areas to speak to, and the operational instructions of any of the included equipment. The team would include items such as the order of presentation, directions

for animation playback and control, and suggested questions and answers. Other program notes provided direction for use of non-visual activities. The program could not consist of just animations and visuals. In order to keep the program interesting and contain relatable information, other kinetic activities were investigated. From all of this CSIRO would then have a complete program to offer to schools.

## 4 Findings

After a thorough exploration of teacher requirements, analysis of previous year 12 VCE chemistry exams, and assessment of VMD, we have identified three key concepts we suggest the program communicate to students: Protein structure and formation, DNA as related to proteins, and rational drug design. Our team then expanded on this information set with recommendations of supporting activities. We continue by recommending several indirect benefits, which should be stressed throughout this program.

Through our interviews, it became apparent that teachers currently use a variety of visual techniques to help students understand biochemistry, ranging from pipe cleaners to YouTube videos. Their current resources varied widely, and the limitations of these various techniques were a source of frustration for many. Pipe cleaners and whiteboard drawings were not adequate tools for presenting this advanced subject matter, teachers said. When presented with CSIRO's proposed biomolecule visualization program, all of the educators showed an enthusiastic response and were keen to see it implemented.

### 4.1 Educational Recommendations

All teachers interviewed expressed how precious their course time is. This was a fundamental constraint when recommending educational material for our new program. This material is extremely complex. A very particular presentation style is required to ensure these concepts are communicated effectively and engage students throughout the program.

#### 4.1.1 Program Alignment and Curriculum Position

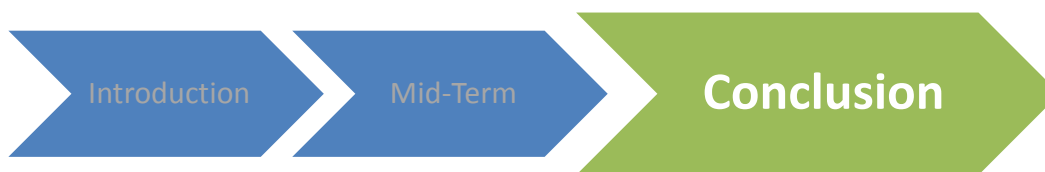


Figure 6 - Curriculum Timeline

Our team recommends that CSIRO's new VCE year twelve chemistry program be constructed as a conclusion to the term. 90% of the teachers interviewed stated that they would prefer to use this program towards the end of the unit. This finding is critical as curriculum position is the basis for the organization of the program. Position dictates what material to present, the depth which the material can take, and how best to present it.

A program delivered towards the end-of-term would be able to accomplish more than an introductory program. Because the students would have a larger knowledge foundation at the end of the term, they would better understand the complex material presented. This program would serve as a critical unit overview before the VCE exam. The program contains information from the entire unit, and would strengthen the students' knowledge before the difficult exam. One teacher stated that she preferred to use CSIRO programs towards the end of a unit, allowing her students to build stronger connections between concepts. She continued, saying that it was not until after a CSIRO program that approximately one third of her students truly understood the material. A program used towards the end of the term would be able to contain more thorough and in-depth material to allow this.

Our interviews also demonstrated how precious time is for VCE courses. Teachers consistently insisted that this program remain relevant to the VCE curriculum, stating how precious class time is. This is further support for having the program as a conclusion because the material can be presented efficiently to students. The program also has much more flexibility at the end of the term. This flexibility



makes it easier for CSIRO to market. Multiple teachers expressed that they would have to see how the program is related to their curriculum before buying the program from CSIRO.

#### 4.1.2 Program Content

The central content of this program should cover protein structure and formation, DNA as related to proteins, and rational drug design. As shown in Figure 7, these topics are closely related, allowing them to be tied together in a helpful and illustrative narrative. Each of these topics is a key component of the VCE Curriculum and students and teachers will benefit from additional visual aid in these areas. These concepts are easily visualized with VMD. Our educator interviews, online surveys, and our VCE literature review all confirm these areas as appropriate program content.

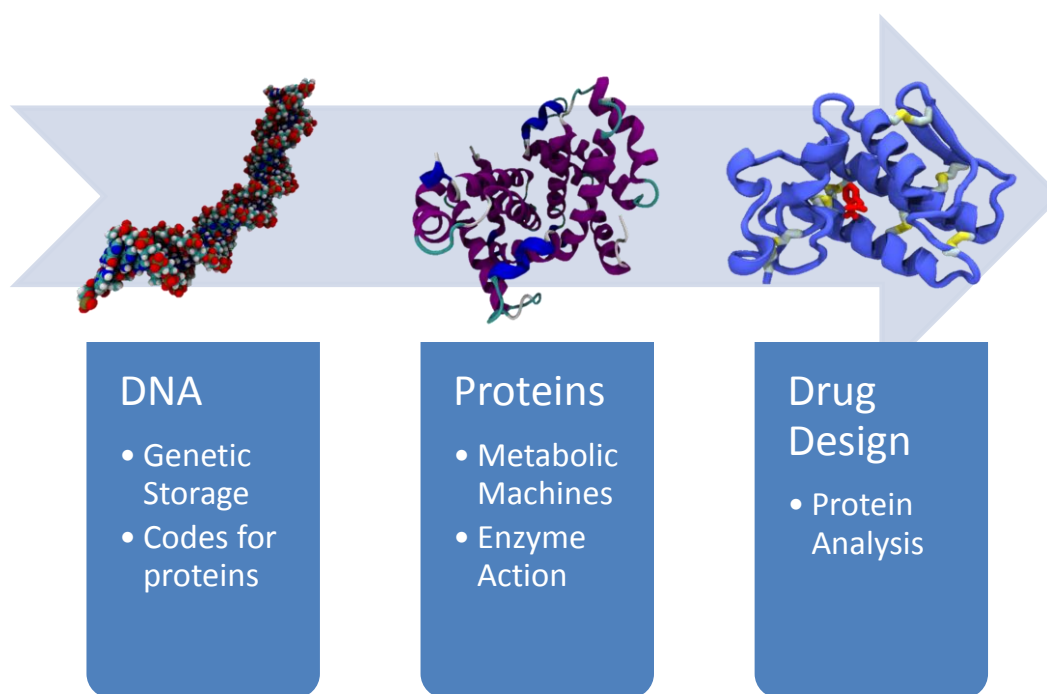


Figure 7 - Program Content Narrative

#### 4.1.2.1 Proteins

Proteins are one of the fundamental building blocks of almost all life on the planet. They are inside every cell in our body, and are critical to all metabolic activity. We recommend that the new education program include information about the structure of proteins. Specifically we suggest teaching the various structure levels (primary, secondary, and tertiary), and how these are affected by bonding. This area of biochemistry has been identified through educator responses and analysis of previous exams.

**Question 5**  
The following is a diagram of a section of a protein chain.

The bonds represented by X and Y are

	X	Y
A.	amide bond	disulfide bond
B.	covalent bond	ionic bond
C.	hydrogen bond	peptide bond
D.	dipole-dipole bond	covalent bond

**Figure 8 - Question 5 from the 2011 VCE exam**  
A question regarding to the bonding forces within the primary structure of a protein.

Proteins are long chains of amino acids, which fold up into various shapes and sizes. The order of these acids and their folded shape give them their unique functionality (Alberts, Bruce et. al. 2004). The VCE exams consistently test students on the formation of amino acids into proteins. On the 2011 VCE exam there were three questions out of a total of 28 which tested knowledge on how amino acids bond. Figure 8 shows Question 5, one of the three amino acid bonding questions from the 2011 VCE exam. As seen, the question requires students to analyze the structure of the given amino acid chain. The exam asks students to identify the types of bonds formed between the indicated amino acids, and respond in multiple-choice fashion. Only 75% of students responded correctly by selecting A.

Question 5 in Figure 8 above only considers a handful of amino acids. As some protein chains can reach thousands of acids long, a more concise method of representation is required. These alternate modes of representation are referred to as the primary, secondary, tertiary, and quaternary structure (Alberts, Bruce et. al. 2004). Figure 9 and Figure 10 show the primary and tertiary structures of hemoglobin, respectively. Both of these graphics were generated with VMD, and are easily animated. Although these images are quite different, they both represent the same fundamental structure. Almost

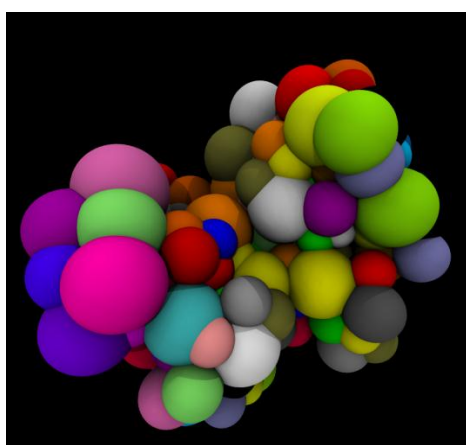


Figure 9 - Hemoglobin Primary Structure

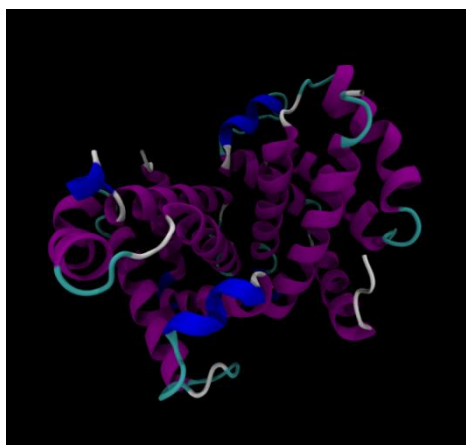


Figure 10 - Hemoglobin Tertiary structure

all of the teachers we spoke to had difficulty conveying this three dimensional structure to their students. As knowledge of protein structure and function is called for directly in the VCE Chemistry Study Design document (Appendix F), we recommend it take a primary role in this new program.

#### 4.1.2.2 DNA

Deoxyribonucleic acid (DNA) holds all the information for reproducing life. DNA consists of four nucleic acids: adenine, cytosine, guanine, and thymine. These four nucleic acids, bond together to form a large chain, with a sturdy backbone. This chain then pairs with a complimentary chain, and spirals to form DNA's familiar double helix structure. The intricate pattern of nucleic acids creates the genetic code for making proteins. We recommend that DNA be included in CSIRO's new program. Specifically, we suggest the program address the structure of DNA and how nucleotides bond to form this structure.

From our exam analysis, we found that students consistently have trouble with DNA related questions. Of the eight DNA related questions from the past four of VCE exams, only two questions were answered correctly by more than 75% of the respondents. Only 50%-75% percent correctly answered the remaining six questions. These six questions focused on DNA structure and nucleotide bonding. Their low success rate shows a clear gap in student's understanding, which our program is well suited to address.

**Question 9**

A piece of double-stranded DNA, which is 200 base pairs in length, contains 50 thymine bases. The number of guanine bases in the piece of DNA is

A. 50

B. 100

C. 125

D. 150

**Figure 11 – Question 9 from the 2008 VCE Exam**

It is relatively simple and only requires students know the basics of nucleotide pairing. 63% of students correctly answered D.

One particular mistake that students made involved introductory material. We suggest that CSIRO have their program include a discussion of the basics of DNA. This can specifically include how nucleotides pair. Adenine and thymine always form a pair in the double helix and cytosine and guanine always form a pair. These base pairs are something that students learn early on and some teachers even said that students are introduced to this in year 10 or 11. The VCE exams consistently have questions related to this. Figure 11 shows one example. Students are required to know which base, or nucleotide, pairs with which one as well as understand that a base pair consists of two nucleotides.

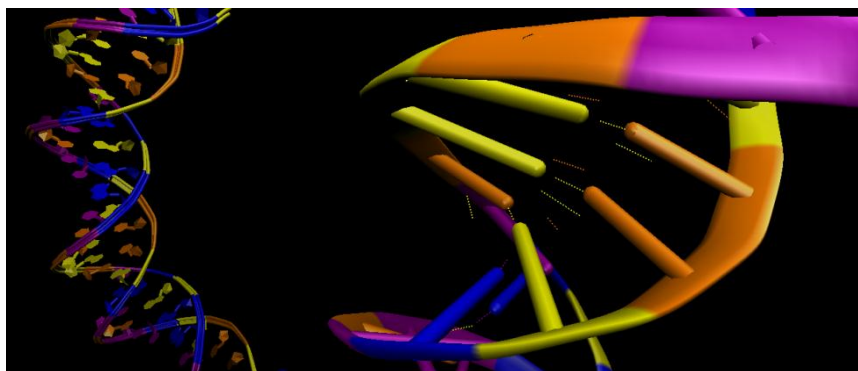


Figure 12 – Two informative VMD renderings of DNA

In order to help students better understand questions like that in Figure 11, we recommend that animations describe nucleotide pairings. As seen in Figure 12, VMD can show individual nucleotides in DNA easily. From there we can isolate a pair and have students really see the bonds that create base pairs. This is also helpful in showing students that adenine and thymine have two hydrogen bonds that hold them together while guanine and cytosine bond using three hydrogen bonds. In fact, question 9b in the open response section of the 2009 VCE Chemistry exam requires this specific knowledge as shown in Figure 13.

The temperature at which 50% of a piece of double-stranded DNA separates into single strands is known as the melting temperature. A certain human viral DNA contains a greater percentage of adenine than a monkey viral DNA. The lengths of the human and monkey viral DNA molecules are equal.

b. Explain why the human viral DNA has a lower melting temperature than the monkey viral DNA.

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Figure 13 - Question 9b from the 2009 VCE Exam.

This question requires students to understand how nucleotides bond.

Based off teacher input we also suggest that there include an animation of DNA splitting into two strands. While DNA is typically thought of as a double helix, it does split into two separate strands

when replicating. This process of DNA replication is typically covered in a biology course. According to teacher interviews approximately half of the students taking VCE Chemistry are also taking VCE Biology. These students would benefit from seeing the connection between chemistry and biology. Showing DNA splitting also helps students in general see the structure better because of how VMD can show the bonds breaking.

#### *4.1.2.3 Enzymes and Rational Drug Design*

Enzymes are a particular type of protein, which act as catalysts, speed up several biological reactions. An enzyme takes a molecule, called the substrate, and converts it into products. An example of this is trypsin, which is an enzyme in the human stomach. Trypsin takes other proteins that you eat and breaks them down into amino acids. There are of course lots of other enzymes in the body that help with digestion. These enzymes are typically described in what is referred to as the “lock and key” model.

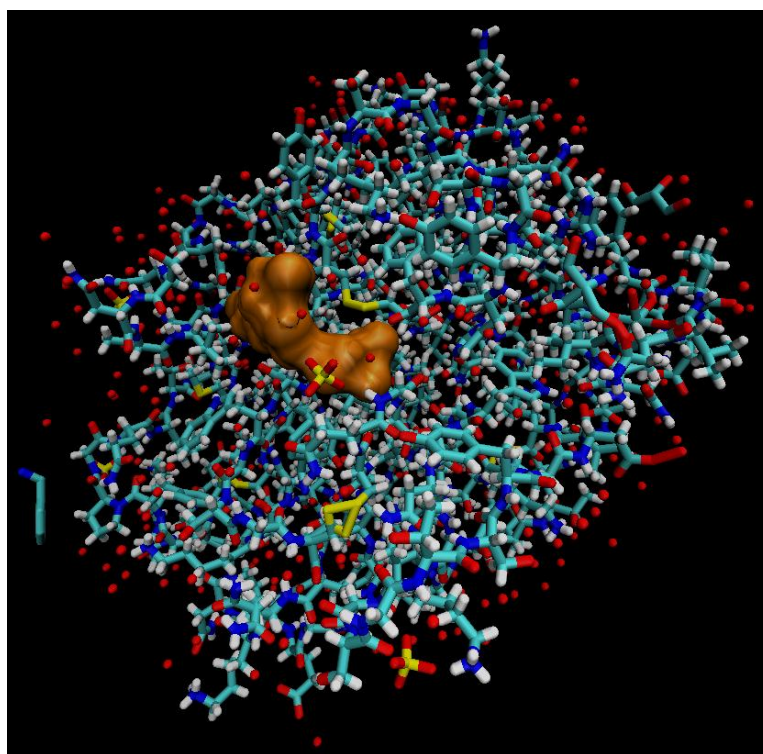


Figure 14 - Trypsin molecule with the active site shown in orange.  
This image was created using VMD.

Enzymes are described using this model because in general enzymes work only with a specific substrate. This specificity is similar to how a key fits only one lock.

The way enzymes work is by having the substrate bond with the enzyme's active site. The active site is typically composed of several amino acids as shown in Figure 14. That active site only makes up a small part of the actual enzyme. Several teachers commented that students do not always understand the relative size of molecules. It is hard to grasp through hand drawn images how small the active site is as well as how small the substrate and products are relative to the size of the enzyme.

We recommend that CSIRO's new program discuss enzymes by improving on the lock and key model. As can be seen in Figure 14, VMD is quite capable of showing the complexities of enzymes. We suggest that an animation of trypsin be used to show students the active site. Additionally this animation can show trypsin unfolded, where the bonds which create the secondary and tertiary structure are broken. This will allow students to see how the amino acids which form the active site are quite far apart in terms of the primary structure.

Enzyme action is closely related to a new topic in the VCE Chemistry curriculum design, rational drug design. Rational drug design is the process of creating new medicine based on the structure and properties of known biomolecules. It is a relatively new addition to the curriculum for year 12 chemistry and has not had any questions directly related to the topic on past exams. The teachers we interviewed said that they often discuss it in terms of Relenza and Tamiflu, both created in Australia. Relenza and Tamiflu are some of the few medicines for after someone gets the flu. Relenza works by preventing the flu virus from spreading to other cells.

We found that teachers do not always have the time to discuss rational drug design with their classes. We therefore suggest that CSIRO include animations of Relenza to supply students with the knowledge that they might be missing in the classroom. Several teachers did also say that they would like to see animations of Relenza because how Relenza works is similar to how enzymes behave. As shown in Figure 15, Relenza has active sites similar to enzymes. The decision to use Relenza instead of Tamiflu is also because CSIRO was a partner in creating Relenza. This makes the material more relevant to students, especially when discussing careers in biochemistry.

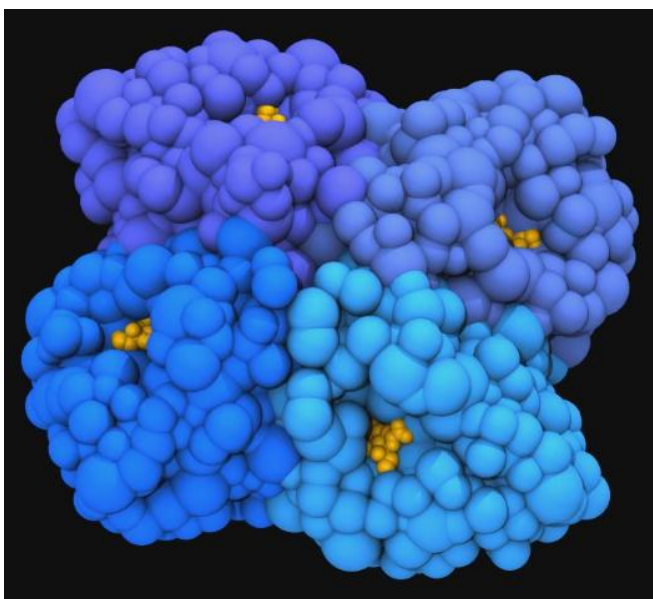


Figure 15 - Rlenza with active sites in yellow.

#### 4.1.3 Going Beyond Animations

After observing many of CSIRO's in house programs, it became clear that our educational program needs more than just animations and visuals. While we have been impressed by VMD's capabilities, we have found that students will need more than just animations to convey these concepts. At our first interview with Martha Cyr, the K-12 outreach coordinator for WPI, we came up with the idea to use 3D models of biomolecules in conjunction with the animations we create. Cyr stated that in order to keep students engaged, their attention must be distributed across multiple mediums. She suggested



trying to create hands on activities to strengthen the material presented from the animations. Luckily, the program VMD can be used to make hands on models with the help of a 3D printer. The team felt that this program needs hands on elements to present the material in multiple mediums.

Along with hand held models, the team recommended that other kinetic activities be used. Caitlin Lewis, our main point of contact at CSIRO, suggested using an activity where the students would represent amino acids forming a protein. The idea the team generated was to have different students link arms representing a chain of amino acids. The chains of students would then walk in and out of each other, and jumble around. Eventually, everyone groups of students would get tangled up with each other. This is a fairly accurate analogy for how proteins form. This idea received positive appraisals from teachers and was also supported by educational research.

By not using only one method to convey information, students will remain focused and absorb more material. Utilizing just animations would only slightly improve upon than the teachers' lectures. The overarching goal of this program is to significantly improve upon the knowledge of the students, farther than that of their teachers' lectures.

#### **4.1.4 Additional Program Benefits**

The above recommendations bring with them several additional benefits. VMD is a professional grade tool, cited in thousands of prominent papers (Papers Citing VMD, 2012). Exposure to this type of technology is a unique experience for any high school student, and is sure to make a lasting impression. This program also brings a unique opportunity to inform students about the breadth of careers available from studying chemistry and biotechnology.

Our team recommends that, during the Rational Drug Design section of this program, the presenter explain Visual Molecular Dynamics, and its purposes beyond the creation of animations. VMD

is a singularly powerful molecular modeling tool, capable of performing complex simulations and calculations. This program's real world applications will not only interest students, but also encourage them to continue investigation into its dozens of other features.

Molecular modeling is only one of the dozens of career applications of biotechnology, an exciting and rewarding field for students to consider. Advanced visuals, such as the ones described above are only possible with the assistance of Computational Molecular Biologists, such as Dr. Mike Kuiper. Our team recommends that CSIRO identify his unique application of chemistry and biology as a prime example of a modern biochemistry profession. We also recommend that this program highlight Rational Drug Design as another possible profession. Drawing these connections between knowledge and application is a critical component to engaging students and showing this field's importance. Both our interview with Martha Cyr and our interviews with educators in Victoria indicate that career applications are valuable to students, and will make for a stronger program overall.

## **4.2 Practical Matters and Program Metrics**

After observing many of CSIRO's in house programs, it became clear that our educational program needs more than just animations and visuals. While we have been impressed by VMD's capabilities, we have found that students will need more than just animations to convey these concepts. At our first interview with Martha Cyr, the outreach coordinator for WPI, we came up with the idea to use 3D models of biomolecules in conjunction with the animations we create. Cyr stated that in order to keep students engaged, their attention needs to be redirected towards multiple mediums. She suggested trying to create hands on activities to strengthen the material presented from the animations. Luckily, the program VMD can be used to make hands on models with the help of a 3D printer. The team felt that this program needs hands on elements to present the material in multiple mediums.

Along with hand held models, the team recommended that other kinetic activities be used. Caitlin Lewis, our main point of contact at CSIRO, suggested using an activity where the students would represent amino acids forming a protein. The idea the team generated was to have different students link arms representing a chain of amino acids. The chains of students would then walk in and out of each other, and jumble around. Eventually, everyone groups of students would get tangled up with each other. This is a fairly accurate analogy for how proteins form. This idea received positive appraisals from teachers and was also supported by educational research.

By not using only one method to convey information, students will remain focused and absorb more material. Teachers also explained to us the physical models they used and some of the difficulties that physical models provide. This information leads us to the recommendation that combining the flexibility provided by 3D animations and the interactivity provided by kinetic activities.

## 5 Conclusions and Recommendations

The goal of this project was for our team to assist CSIRO Education with the design of their new informal education program. Utilizing the latest in 3D projection technology, this new program will help students see activity on the sub-cellular level. The images on screen will move and shake much like their microscopic counterparts in order to accurately portray several complicated concepts. Not only will this program help students understand the material, it will help demonstrate biochemistry's broader implications. This program will demonstrate several interesting career opportunities, and motivate students in their science studies.

During the course of the project, our team set out to answer key questions about this program's implementation. First, the team had to identify the key concepts of VCE chemistry, Unit 3-Area of Study 2, to communicate to students. Certain teachers expressed difficulty teaching specific areas of the unit, and our team set out to determine what sections needed extra attention for the program. Our next objective was to identify the constraints imposed by the teachers' curriculums. The team had to determine what metrics the program had to be able to fit, in order for teachers to be able to hire CSIRO. Our last objective was to determine the features and limitations of Visual Molecular Dynamics. VMD was the proposed visualization program, and the team had to identify the specific features of it to be implemented into the educational program.

In order to answer the questions above, we interviewed ten VCE Chemistry teachers and two former VCE Biology teachers. These interviews served as our primary source of information guiding our program recommendations. We also constructed a matching electronic survey and distributed it to twelve teachers who were unavailable to meet in person. The team also analyzed all VCE Chemistry Unit 3 exams since 2008. We reviewed questions relating to biomolecules, and examined the questions that

proved difficult for many students. These methods, augmented by continued literature review have aided the team in making the following recommendations about this new programs implementation.

- Construct the program as a conclusion to VCE Unit 3, Area of Study 2
- Primary course Material should include:
  - The three dimensional structure of proteins and corresponding structural representations (primary, secondary, tertiary)
  - The formation and function of DNA
  - The concepts of protein analysis as used in rational drug design
- VMD poses no technological limitations and will meet all requirements of this program
- The program should include supporting activities to compliment the 3D animations

## 5.1 Program Recommendations

One important consideration addressed in our interviews was the chronological position of our program in the term. We recommend designing this program as a conclusion to the VCE Chemistry unit, where much less introductory material would be required. This wrap-up style program would allow the animations to take center stage, incorporating more in depth material. Many teachers stated that their VCE chemistry students do not see the correlation between sciences and possible careers. If the program were presented towards the end of term, students would be able to draw connections between the information and possible career options. The program would help students solidify the concepts learned in class, and would serve as a helpful review before the exam.

The chronological position of our program has a serious impact on its contents. We suggest that the program cover proteins and protein structure, DNA, and rational drug design. The concepts included in each of these areas were identified through teacher feedback and the previous exam analysis. According to almost all teachers interviewed, students have difficulty understanding the three dimensional shape of proteins. To combat this, we suggest a detailed animation be constructed detailing the various structure levels of proteins, and the forces which create them. These concepts would be expanded upon to describe the operation of DNA, and how protein analysis is used in rational drug

design. The proteins in question must also be carefully selected. Our literature review indicates that students look for real-life implications for their studies. This in mind, we suggest animating one of the many important proteins in the body, such as hemoglobin or trypsin.

To create the animations described above, the team carefully evaluated Visual Molecular Dynamics, a free molecular visualization program from the University of Illinois. Working closely with Dr. Mike Kuiper, a computational molecular scientist from the Victorian Life Sciences Computation Initiative (VLSCI) the team assessed VMD's strengths and weaknesses. After tutorials given by Dr. Kuiper, the team can confidently say that VMD poses no serious limitations to the creation of animations for our program. We have taken note of several useful rendering methods and have included them as the basis for all of our storyboards.

While we have been impressed by VMD's capabilities, we have found that students will need more than just animations to convey these concepts. At our first interview, with the outreach coordinator for WPI, we came up with the idea to use 3D models of biomolecules in conjunction with the animations we create. Additionally Caitlin Lewis, our main point of contact at CSIRO, suggested using a kinetic activity such as having the students represent amino acids forming a protein. These additional techniques received positive appraisals from teachers and are also supported by educational research. By not using only one method to convey information, students will remain focused and absorb more material. Teachers also explained to us the physical models they used and some of the difficulties that physical models provide. This information leads us to the recommendation that combining the flexibility provided by 3D animations and the interactivity provided by kinetic activities is the best way for this program to be created.

The team found that the program should be designed around an audience range of 15 to 45 students. The average VCE chemistry class held about 18 students. Most schools only had two or three

chemistry courses. In an effort to keep costs down, many teachers had previously combined their classes for CSIRO programs. Because of this, the program needed to be able to hold up to about 45 students. It would be unfeasible to have an audience much larger than 45 due to cost of equipment. Also, with a larger audience, the educational value would be less of that than a smaller audience. It was deemed unlikely that a program would have an audience smaller than 15 students. The cost would be too great to have an audience that size.

The team found that the program should cost schools between 20 to 30 dollars per student. As most current CSIRO programs cost somewhere in this range, many of the teachers interviewed would be able to afford this. Ultimately, CSIRO needs to cover its own expenses. Most teachers and schools are fine with paying this amount for an educational program. Some have even stated that if the educational value were worth it, cost would not be a factor in their decision to hire CSIRO. However, most of the schools comfortable with spending money on educational programs were private schools. In the past CSIRO has worked with RMIT to bring educational programs to underprivileged schools that normally could not afford them. RMIT paid for the programs, and the schools received an educational experience that they would normally not have been able to receive. Because of this, the team recommended that CSIRO continue to arrange sponsored program sessions as much as possible. That way, CSIRO would be able to cover its own expenses, while educating more eager students. This program will have content valuable to any VCE Chemistry student, and should not be inhibited by cost.

## 5.2 Moving Forward

As you can see, this program is not complete. During our time on site, we focused on gathering input from educators around Melbourne. We have taken this information, along with analysis of the supporting VCE documents, and created a list of recommendations for this programs construction. Moving forward, we recommend that CSIRO continue their relationship with Dr. Mike Kuiper, and begin

creating the animations described in this document. Continued work is needed to generate supporting materials, such as 3D prints of various proteins, worksheets for students to complete during the program, and any materials needed for advertising. During our interview process, teachers requested supporting material as a take-away from the program. Many teachers requested copies of the videos from the program itself, for use in their coursework. As this contains valuable proprietary data, CSIRO should carefully consider what, if anything, should be given.

This document and all supporting materials should function as a guide for the new 3D Biomolecules program. When fully implemented, this program will serve as a valuable asset to any chemistry teacher. The topics are not only relevant to the VCE curriculum, but engaging for students of various backgrounds. It will show them the power in the field of biochemistry, and give them firsthand experience with a professional molecular modeling tool. It will demonstrate many complex concepts to students in several easily understandable formats, helping to make biochemistry a more accessible and exciting field.



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## Appendix A – Project Proposal

# CSIRO Education (Victoria) 2012 Proposal

### Educational Program Development – 3D Biomolecules

CSIRO Education has a rich history of providing high quality science programs across all levels of primary and secondary schooling. Each year CSIRO Education presents programs to more than 60,000 students in Victoria and more than 320,000 students across Australia.

CSIRO Education's post compulsory programs support the final stage of school education. Our programs make clear links between "textbook" science, the relevant curriculum and thought-provoking contemporary research and innovation. They provide access to specialised equipment, materials or techniques unavailable in most school laboratories.

We are currently preparing a new program to support VCE Chemistry teachers in the teaching of biomolecular structure and function. Using molecular modeling software, a variety of animations and interactive models will be created, which will be presented in the classroom using a 3D projection system. We envisage the content to cover topics such as the structure and function of DNA, RNA and proteins, the function of enzymes and rational drug design.

We are keen for WPI students to participate in the planning stages of this program's development. You will look at the curriculum material, interview teachers to find out their specific needs, and work with our computational collaborators in preparation of sample animations. This project would suit anyone with an interest in chemistry, biochemistry, computer animation or educational programs.

## Appendix B – Interview Guidelines

# Educator Interview

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*Team CSIRO*

*Date:* \_\_\_\_\_

*Interviewee:* \_\_\_\_\_

*Location:* \_\_\_\_\_

Hello. Our names are Caleb, Daniel and Jeff. We are university students from Worcester Polytechnic Institute in America. We are currently working with the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to help design a new educational program. The program is targeted at year 12 students studying VCE Chemistry (Unit 3- Area of study 2). The program will be specifically about the primary, secondary, and tertiary structures of proteins, as well as DNA and other biomolecules. In the past, students have stated that it is very difficult to visualize these rather complex concepts. Our program will incorporate a 3 dimensional projection system to show animations of these molecular interactions, and could include other hands on learning opportunities. Our ultimate goal is to provide VCE chemistry students with a stronger and more thorough knowledge of these difficult biochemistry concepts.

1. What tools do you use to teach students about DNA, proteins and enzyme action etc.?
  - a. Textbook pictures, YouTube videos, lectures, practical experiments, computer modeling, other multimedia?
  - b. What is your average Bio class size?
2. Have you had any difficulty teaching this particular section? If so, in what area/ which concept? What was difficult about it?
3. By the end of the unit, how firm a grasp do your students have of the structure and functionality of proteins and DNA? How comfortable with the material are they? Do they have an understanding beyond what is required by the VCE?
4. Are there any proteins or enzyme interactions you usually use to help illustrate these concepts?
  - a. What proteins/enzymes would you want to see?



5. Suppose CSIRO had a new interactive Biomolecules program which focused on helping students visualize the complex behaviors of proteins and DNA. It would use multiple methods to describe several key areas of VCE Unit 3, Area of Study 2. Primarily through the use of interactive 3D projections of molecular models (animations).

Selling points: curriculum relevance, engagement of students, presenter with higher education in area, advanced technology (in a format closer to their personal interests/view of the world), demonstration of a real-life cutting edge research tool, research links, career links, teacher support materials.

Which of these are of most significance to you? Are any irrelevant?

- a. What features would you like this program to have?
  - i. Duration of program?
  - ii. Number of students it can hold?
  - iii. Cost?
- b. Would you consider including this in your curriculum?
- c. Chronologically, where in the teaching unit would you like to use it? (eg as a introduction, a wrap-up/summary or in the middle as you're teaching it)
- d. How prepared would your students be at that time for this kind of material? (i.e. How much background material would need to be presented?)

## Appendix C – Electronic Questionnaire

### CSIRO Program Survey

Exit this survey

### CSIRO Program Survey

Hello and thank you for taking the time to answer our brief survey. Please be assured that all answers will be kept confidential, though you may be quoted in our paper. If you would not mind us including your name, please say so in the comments at the end of this survey.

**\* 1. What is the name of your school?**

**2. How many students are in your average VCE Chemistry class?**

Next

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**3. What tools have you used to teach your students about DNA, proteins, enzyme action etc.?**

Classroom Discussion

Textbook Images

Practical Experiments

Videos (DVD, YouTube etc.)

Computer Modelling

Other (please specify)

**4. Have you had any difficulty teaching any particular concepts? If so, what concepts proved difficult?**

**5. Please rate how strongly you agree with the following statements.****By the end of this unit...**

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	N/A
Most of my students have a very firm grasp of the subject material						
Most of my students understand the structure and functionality of proteins and DNA						
Most of my students have not simply memorized definitions, but understand the material at a fundamental level						
Most of my students are able to apply the skills they have learned in other areas						

Most of my students  
have learned material  
beyond what is required  
for the VCE Exam

**6. Please list any proteins or enzyme actions that you typically use as examples in class. Are there any (likely more complex) examples you would like to see animated on-screen?**

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## Proposed CSIRO Program

Suppose CSIRO had a new 3D Biomolecules program which focused on helping students visualize the complex behaviors of proteins and DNA. It would use multiple methods to describe several key areas of VCE Unit 3, Area of Study 2. Primarily through the use of interactive 3D projections of molecular models (animations).

### 7. Which benefits of the above proposed program do you find most significant? (Select all that apply)

Curriculum Relevance

Student Engagement

Presenter with Higher Education Qualifications in the area

Demonstration of a real research tool

Research Links

Career Links

Teacher Support Materials

Other (please specify)

### 8. What features would you like this program to have?

Duration of the program  
(in minutes)

Minimum class size

Cost (per student)

### 9. Would you consider including this program in your teaching plan? Why or why not?

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Next

Thank you!

Thank you for your time and energy. The survey is now complete.

If you have any further questions, please leave them in the box below or email [WPICSIRO@wpi.edu](mailto:WPICSIRO@wpi.edu)

**10. Comments, Questions, and Concerns**

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Done

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# Appendix D – 2011 VCE Chemistry Assessment Report

## 2011 Assessment Report



2011

Chemistry GA 1: Written examination 1

### GENERAL COMMENTS

A total of 9048 students sat the June 2011 Chemistry examination. Overall, students performed well. A score of just over 85 per cent was needed for an A<sup>+</sup>, while a score of just over 79 per cent was needed to receive an A. The mean score for the examination was 60 per cent, which corresponded to the middle of the C<sup>+</sup> grade range. These statistics suggested that the examination proved to be slightly more challenging than the corresponding 2010 examination. However, the vast majority of students were able to finish the examination, to the best of their ability, within the allotted 90 minutes.

There were significant instances in which students did not make effective use of supplied data or information; for example, in Section A, Question 13. One of the aims of the study is that students are able to apply their understanding of chemistry to both familiar and new situations.

In Section A, there were 11 questions that more than 60 per cent of students answered correctly, and five questions that less than 50 per cent of students answered correctly.

Question 8 proved to be the most difficult question in this section. The majority of students proceeded along the carboxyl + amino → peptide path without considering the requirement that the product, ibuprofen lysine, needed to be **more** soluble in water than ibuprofen. The question required students to recognise that a deprotonated carboxyl group increases solubility, a point associated with 'soluble' aspirin.

For Question 9 it was decided that two responses could be correct since it was not made clear in the question that the ethanol would most likely be in excess. Even with this allowance, it was evident that the properties of the reactants, products and the catalyst in biodiesel production were not well understood.

While students would have performed titrations as part of their practical work throughout the unit, understanding of the 'equivalence point' was not strong. This was particularly evident in Question 11.

Question 13 emphasised the importance of not only reading the question carefully, but also using the supplied data effectively. The term 'heated to constant mass' may have encouraged many students to assume that all the water was driven off the sample. However, a quick check of  $n(\text{H}_2\text{O})$  removed showed that this was not the case.

The overall performance on Question 15 was surprising. Many students simply did not make the required use of the ratio  $n(\text{NaN}_3)/n(\text{N}_2)$ .

Question 18 challenged students to consider the key factors that determine the IR absorption band for a covalent bond. These factors include bond strength and the relative masses of the two atoms in the bond. Overall question performance showed that most students were drawn to electronegativity as the key factor. Understanding of the principles of spectroscopy is part of the study.

Question 20 showed that students' understanding of the effect of light from the light source on the metal atoms in the flame of an atomic absorption spectrometer could be improved. It suggested that many students did not make the distinction between oxidation and the transition of electrons to higher energy levels due to the absorption of energy.

As a part of their examination preparation, students should be encouraged to critically review multiple-choice questions on which they struggle. Teachers are encouraged to provide critical analysis and feedback to their students on their performance on multiple-choice questions.

Section B provided students with a mixture of question types and a wide variety of challenges.

Performance on Question 1d. reiterated the impression that biodiesel is a topic worth addressing. Question 1f., also linked to fatty acids, required students to recognise the need to use the ratio  $n(\text{Br}_2)/n(\text{compound})$  to determine the number of C=C bonds present in each molecule and then identify which of the three fatty acids in the list qualified.

Responses to Question 2 demonstrated the challenges that descriptive responses pose for some students. It appears that the message about the need for a (+) charge on species causing peaks on a mass spectrum is not yet well known.

## 2011 Assessment Report

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Question 2a.ii. emphasised that interpretation of the supplied data, in this case the mass spectrum, in terms of the context of the question is a challenge for a significant proportion of students. Many misread or misunderstood the label on the y-axis, while others focused on the relative abundances of the atoms rather than the molecular ions. Question 2b. was well handled. Most students were able to link the information provided on the  $^1\text{H}$  NMR spectrum to molecular structure. Students continued to respond well to questions on NMR spectroscopy.

In answering Question 3c. most students focused on the truncated peak on the espresso coffee chromatogram and ignored the presence of the peak area in the data table. Students need to be aware that, when suggesting that a solution should be diluted, it is appropriate that parameters be set. For example, in Question 3c. 'to bring the peak area within the range of the calibration graph'.

Question 4a. was a stoichiometry question that included much data. The challenge for students was to identify the data relevant to getting to the solution most efficiently. Confusion resulted for those students who felt the need to use all the data. In preparing for examinations students should be encouraged to think through the calculation steps before beginning a solution, rather than just using the data in the order in which it appears. In Question 4b. most students interpreted the question as if the moisture in the original precipitate (in 4a.) had been an experimental error. The intent of the question was that both techniques, in 4a. and 4b., were valid, deliberate and accurate. Consequently, the calculated percentage  $\text{P}_2\text{O}_5$  should have been the same for both techniques.

Question 5a. assessed students' ability to write and combine half-equations. This is a skill that is regularly assessed and with which students are expected to be proficient. Many students who provided a correctly balanced oxidation half-equation in Question 5a. did not accurately combine it with a given reduction half-equation in 5a.ii.

Question 5b. was a stoichiometry question that was handled much better than Question 4a. Students seemed more comfortable with titration-based calculations. With calculations related to back-titration, students should use labels such as 'supplied', 'excess/unreacted' and 'reacted/reacting' appropriately. In Questions 5b.i. and 5b.ii. it was necessary to work out the number of mole of  $\text{Cr}_2\text{O}_7^{2-}$  three times.

Question 7a. provided students with an organic reaction pathway. The associated questions revealed some significant issues. Question 7a.ii. required students to draw a structure of an alcohol produced from a chloroalkane. Errors included the incorrect number of carbon atoms and inappropriate representation of the bond between the hydroxyl group and carbon.

Questions 7a.iii. and 7a.iv. related to the use of correct systematic nomenclature. In the chemical name 3-methylbutan-1-ol (3-methyl-1-butanol), the numbers 1 and 3 are an essential part of the systematic name and are used because alternative locations of the methyl and/or hydroxyl groups would represent a different compound. On an ethanol molecule there is no other possible location but C-1 for the hydroxyl functional group so there is no number in the systematic name. Many students incorrectly included the number.

In Question 7a.v., while  $\text{H}_2\text{SO}_4$  or  $\text{H}_2\text{SO}_4(\text{l})$  were acceptable as representing 'concentrated' sulfuric acid,  $\text{H}_2\text{SO}_4(\text{aq})$  was not.

Responses to Question 7b. suggested that, on seeing the words 'fractional distillation' in the question, many students immediately defaulted to the fractional distillation of crude oil and fractionating towers rather than addressing the fundamental principles of fractional distillation as it applies to a range of separations or, in this case in particular, the collection of an ester. Discussion of the method of collection of an ester and separation of an ester from water and unreacted acid and alcohol is a logical adjunct to coverage of ester production. This question tested students' ability to apply their understandings in different situations. The key factor determining different boiling temperature in a mixture of substances is intermolecular attraction.

Question 7c. proved challenging for a majority of students. The requirement to 'explain how the evidence provided by the spectra indicated that a complete separation of banana oil from the reaction mixture had been achieved' was not well interpreted. Some students were able to draw links between the alcohol IR spectrum and the banana oil IR spectrum to argue for separation from the alcohol, but few were able to effectively argue for separation from the acid. A useful ensuing discussion point might have been how the information on the ester spectrum alone shows separation from the acid and the alcohol.

In Question 8c. the main errors were not 'showing all bonds' and not showing the amino group as protonated.



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## SPECIFIC INFORMATION

### Section A – Multiple-choice questions

The table below indicates the percentage of students who chose each option. The correct answer is indicated by shading.

Question	% A	% B	% C	% D	% No Answer	Comments
1	75	5	13	7	0	Ethanol ( $\text{CH}_3\text{CH}_2\text{OH}$ ), ethylamine ( $\text{CH}_3\text{CH}_2\text{NH}_2$ ), and ethanoic acid ( $\text{CH}_3\text{COOH}$ ) all dissolve in water via hydrogen bonding. Ethane ( $\text{CH}_3\text{CH}_3$ ) is non-polar and is less soluble in water.
2	3	80	12	5	0	
3	2	2	95	1	0	
4	12	8	73	7	0	The molecular formula of 2,2,4-trimethylpentane is $\text{C}_8\text{H}_{18}$ .
5	76	12	9	4	0	X is the bond between amino acid residues in the primary structure of the protein. This covalent bond between C and N in the linking peptide group is also known as an amide bond. Y is the bond formed when $-\text{SH}$ on the side groups of cysteine molecules reacts in establishing the tertiary structure of the protein. The covalent S–S bond formed is also known as a disulfide bond.
6	15	19	8	58	1	All amino acids contain the amino, $-\text{NH}_2$ , group, which is basic and would be expected to react with 1.0 M $\text{HCl}(\text{aq})$ .
7	6	7	79	8	0	X – 1,1,2-trichloroethene Step 2 is a substitution reaction, H substituted by Br.
8	7	10	77	6	0	Ibuprofen lysine is more soluble in water than ibuprofen. So when ibuprofen reacts with lysine the product, ibuprofen lysine, must have a structure that enables it to dissolve in water more readily than ibuprofen.  Option C would result from a condensation reaction between the $-\text{COOH}$ group on ibuprofen and the $\alpha\text{-NH}_2$ group on lysine. The product would dissolve in water via hydrogen bonding. Option D would result from an acid-base reaction between the $-\text{COOH}$ group on ibuprofen and the $\alpha\text{-NH}_2$ group on lysine. This product would dissolve in water via ion-dipole bonding and hydrogen bonding. The negative ion, formed when ibuprofen molecules donate $\text{H}^+$ , dissolves via ion-dipole bonding. The positive ion, formed when lysine molecules gain $\text{H}^+$ , dissolves via ion-dipole and hydrogen bonding. Since ion-dipole bonding is stronger than hydrogen bonding, option D best showed the structure of ibuprofen lysine.
9	38	31	17	14	0	The biodiesel ethyl stearate is produced via the reaction: canola oil + 3 ethanol $\rightarrow$ 3 ethyl stearate + glycerol in the presence of potassium hydroxide catalyst.

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Question	% A	% B	% C	% D	% No Answer	Comments
						Since the ethyl stearate is collected in layer A, layer B must contain glycerol, potassium hydroxide and unreacted ethanol. This separation reflects the non-polar nature of the biodiesel as distinct from the polar ethanol and glycerol, and ionic KOH. On this basis, the correct answer was option D. Ideally, the ethanol should be in excess to ensure complete reaction of the canola oil. However, this was not made clear in the question, and it was possible that students may have assumed that the ethanol and canola oil were present in the exact stoichiometric ratio for complete reaction. In this case, layer B would contain only glycerol and potassium hydroxide. Hence, option A was also accepted as correct.
10	8	56	27	10	0	Consider the amounts of $\text{CH}_4$ and $\text{CO}_2$ produced starting from 1 mol $\text{C}_6\text{H}_{12}\text{O}_6$ . Step 1: products are 2 mol $\text{CH}_3\text{CH}_2\text{OH}$ + 2 mol $\text{CO}_2$ Step 2: all the $\text{CH}_3\text{CH}_2\text{OH}$ from step 1 is converted to $\text{CH}_3\text{COOH}$ , hence 2 mol $\text{CH}_3\text{CH}_2\text{OH} \rightarrow 2 \text{ mol CH}_3\text{COOH}$ Step 3: 2 mol $\text{CH}_3\text{COOH}$ $\rightarrow 1 \text{ mol Ca}(\text{CH}_3\text{COO})_2 + 1 \text{ mol CO}_2$ Step 4: 1 mol $\text{Ca}(\text{CH}_3\text{COO})_2$ $\rightarrow 2 \text{ mol CH}_4 + 1 \text{ mol CO}_2$ Total $n(\text{CO}_2)$ produced = 4 mol $n(\text{CH}_4)$ produced = 2 mol Ratio $n(\text{CH}_4)$ produced : $n(\text{CO}_2)$ produced = 2:4 = 1:2 Since the $\text{CH}_4$ and the $\text{CO}_2$ may be assumed to be collected at the same temperature and pressure, the ratio $V(\text{CH}_4)$ produced: $V(\text{CO}_2)$ produced equals 1:2.
11	17	45	32	6	0	When a strong base such as $\text{NaOH}(\text{aq})$ is added to an acid, weak or strong, the key factor influencing the amount of $\text{NaOH}(\text{aq})$ required to reach the equivalence is the $n(\text{H}^+)$ available from the acid. Since there was 25.0 mL of both acids, and both were 0.10 M $n(\text{acid})$ present $= 0.10 \times 25.0 \times 10^{-3}$ $= 2.0 \times 10^{-3} \text{ mol}$ Both acids are monoprotic, so the $n(\text{H}^+)$ available for titration is the same for each acid. Hence, the same amount of 0.20 M $\text{NaOH}(\text{aq})$ is required to reach the equivalence point for both acids. Representing the acids by the general formula $\text{HA}(\text{aq})$ , the equation for the titration reaction in both cases is $\text{HA}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{NaA}(\text{aq}) + \text{H}_2\text{O}(\text{l})$ Since the $n(\text{HA})$ is the same for both acids, the $n(\text{NaOH})$ required is the same for both acids.
12	12	15	61	12	0	This question required students to make effective use of the information in Table 11 of the Data Book (Acid-base Indicators). According to the information in the table: Thymol blue is yellow above $\text{pH} = 2.8$

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Question	% A	% B	% C	% D	% No Answer	Comments
						<p>Methyl red is yellow above pH = 6.3 Phenolphthalein is colourless below pH = 8.3 This suggests that the pH of the solution was above pH = 6.3 and below pH = 8.3, i.e. between pH = 6.3 and pH = 8.3.</p> <p>Overall performance on this question suggested that a significant number of students were unable to effectively interpret the information in Table 11 of the Data Book. Teachers should ensure that students use the Data Book throughout the study.</p>
13	33	38	14	14	1	<p><math>n(\text{CaSO}_4 \cdot 2\text{H}_2\text{O}) = 172.1/172.1 = 1.000 \text{ mol}</math></p> <p>The loss in mass during heating was due to the release of <math>\text{H}_2\text{O}</math>. <math>n(\text{H}_2\text{O}) \text{ released} = 27.0/18.0 = 1.50 \text{ mol}</math></p> <p>The ratio <math>n(\text{CaSO}_4 \cdot 2\text{H}_2\text{O}) \text{ reacting} : n(\text{H}_2\text{O}) \text{ released} = 1:1.5 = 2:3</math></p> <p>So the coefficients of <math>\text{CaSO}_4 \cdot 2\text{H}_2\text{O}</math> and <math>\text{H}_2\text{O}</math> in the equation must be in the ratio 2:3. Alternatively, 1 mol <math>\text{CaSO}_4 \cdot 2\text{H}_2\text{O}</math> releases 1.5 mol <math>\text{H}_2\text{O}</math>, leaving <math>2 - 1.5 = \frac{1}{2} \text{ mol}</math> <math>\text{H}_2\text{O}</math> remaining in the hydrated compound, so the chemical formula of the product of the reaction must be <math>\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}</math>. This is consistent with the equation <math>2\text{CaSO}_4 \cdot 2\text{H}_2\text{O}(\text{s}) \rightarrow 2\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}(\text{s}) + 3\text{H}_2\text{O}(\text{l})</math>.</p>
14	6	14	18	61	1	<p><math>d(\text{gas}) = 2.86 \text{ grams per litre at STP}</math> Volume of 1 mol gas at = 22.4 L Hence the <math>M(\text{gas}) = 2.86 \times 22.4 = 64.1 \text{ g mol}^{-1}</math> <math>M(\text{SO}_2) = 64.1 \text{ g mol}^{-1}</math></p>
15	28	59	10	3	1	<p>The inflation of the airbag to 62.0 L was due to the release of <math>\text{N}_2(\text{g})</math>; i.e. the <math>V(\text{N}_2)</math> present at 100 kPa and <math>36.6^\circ\text{C} = 62.0 \text{ L}</math> <math>n(\text{N}_2) \text{ produced} = P(\text{N}_2) \times V(\text{N}_2)/RT = 100 \times 62.0/[8.31 \times (36.6+273)] = 2.41 \text{ mol}</math></p> <p>According to the equation for the reaction <math>n(\text{NaN}_3)/n(\text{N}_2) = 10/16 = 5/8</math> Hence <math>n(\text{NaN}_3) = (5/8) \times n(\text{N}_2) = (5/8) \times 2.41 = 1.51 \text{ mol}</math> <math>m(\text{NaN}_3) = n(\text{NaN}_3) \times M(\text{NaN}_3) = 1.51 \times 65.0 = 97.9 \text{ g}</math></p>
16	2	69	25	3	0	<p>If the starch molecule is formed from 500 <math>\text{C}_6\text{H}_{12}\text{O}_6</math> molecules, 499 <math>\text{H}_2\text{O}</math> molecules will be produced during the condensation polymerisation reaction. <math>M(\text{starch}) = 500 \times M(\text{C}_6\text{H}_{12}\text{O}_6) - 499 \times M(\text{H}_2\text{O}) = 500 \times 180.0 - 499 \times 18.0 = 90000 - 8982 = 81018 \text{ g mol}^{-1}</math> Option C (<math>90\,000 \text{ g mol}^{-1}</math>) overlooked the</p>

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Question	% A	% B	% C	% D	% No Answer	Comments
						condensation nature of the formation of starch from glucose.
17	71	11	6	12	0	In thin-layer chromatography, the stronger the adsorption to the stationary phase, the smaller the distance travelled up the stationary phase and the lower the $R_f$ value.
18	51	20	17	11	1	<p>At ordinary temperatures covalent bonds vibrate, and the vibrational energies of molecules have defined energy (quantum) levels (states) in the same manner as electronic energy levels. Transitions between vibrational energy levels depend on absorption of infrared radiation of energy matching the difference between vibrational energy levels. The energy absorbed is proportional to the frequency of the IR radiation, which is proportional to the wavenumber. Covalent bonds in molecules are not rigid, but may be compared to stiff springs that can be stretched and bent.</p> <p>The exact frequency (wavenumber) at which a given vibration occurs is determined by the strength of the bonds involved and the masses of the atoms in the bond.</p> <p>C-H bonds (bond energy <math>410 \text{ kJ mol}^{-1}</math>) are stronger than C-O bonds (bond energy <math>326 \text{ kJ mol}^{-1}</math>).</p> <p>The mass effect can be attributed to the 'different' atom in the C-O and C-H bonds. The lighter H atom produces a higher vibration frequency, so the IR radiation required to bring about the transitions to higher vibrational energy levels in C-H bonds will be of higher wavenumber than for C-O bonds.</p> <p>So, the lower IR wavenumber for bond stretching in a C-O bond can be attributed to larger atomic mass of oxygen atoms compared to hydrogen atoms.</p>
19	26	6	5	62	0	A mixture of hydrocarbon molecules would be quite volatile and most effectively separated into its component compounds by gas chromatography. Each component could then be identified by mass spectroscopy.
20	12	40	29	18	0	<p>Aqueous solutions containing the <math>\text{Cu}^{2+}(\text{aq})</math> ion are blue because in the presence of white light they absorb wavelengths in the red region of the visible spectrum, and so transmit wavelengths in the blue region.</p> <p>When <math>\text{CuSO}_4(\text{aq})</math> is introduced into an atomic absorption spectrometer, the sample is atomised in the high temperature flame. As the light from the Cu lamp passes through the flame, electrons in the Cu atoms in the flame absorb energy and are promoted to higher energy levels, but are not lost from the atoms. As excited electrons return to lower energy levels, energy emitted is in the green region of the visible spectrum.</p> <p>Because the absorption of energy by the Cu atoms in the flame from the light source does not cause</p>

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Question	% A	% B	% C	% D	% No Answer	Comments
						loss of electrons from the atoms, oxidation does <b>not</b> occur.

### Section B – Short answer questions

For each question, an outline answer (or answers) is provided. In some cases the answer given is not the only answer that could have been awarded marks.

#### Question 1

With the exception of Questions 1d. and 1f., this question was well done.

##### 1a.

Marks	0	1	Average
%	10	90	0.9

A

##### 1b.

Marks	0	1	Average
%	14	86	0.9

H

##### 1c.

Marks	0	1	2	Average
%	10	28	63	1.6

D and E

##### 1d.

Marks	0	1	Average
%	64	36	0.4

F

Most students overlooked the fact that biodiesel is generally a methyl ester of a fatty acid. Structure F was the only ester in the table of structures provided. Structure E was chosen by many students, indicating that they did not realise that while glycerol is a product of the production of biodiesel by transesterification it is **not** a component of biodiesel.

##### 1e.

Marks	0	1	Average
%	15	85	0.9

B

##### 1f.

Marks	0	1	Average
%	65	35	0.4

F

Students needed to realise that to react with Br<sub>2</sub> the substance had to contain C=C bonds; that is, carbon-carbon double bonds.  $n(\text{Br}_2)_{\text{reacting}} = 0.320/160.0 = 0.002 \text{ mol}$ . Since 0.001 mol of the substance reacts **completely** with 0.002 mol Br<sub>2</sub>, each molecule of the substance must contain two C=C bonds. A similar calculation was required on the 2009 examination.

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There were three fatty acids in the table; options D, F and G (see below). Saturated fatty acids have the general formula  $C_nH_{2n+1}COOH$  or  $C_nH_{2n}O_2$ . Unsaturated fatty acids with the same number of C atoms as a saturated fatty acid have two fewer H atoms for each C=C present. Therefore,

- D.  $C_{13}H_{27}COOH$  – saturated  
F.  $C_{17}H_{31}COOH$  – polyunsaturated with 2 C=C bonds  
G.  $C_{17}H_{29}COOH$  – polyunsaturated with 3 C=C bonds

### Question 2

2ai.

Marks	0	1	Average
%	42	58	0.6



Students did not perform as well as expected on this question. Students need to be aware that the species producing peaks on a mass spectrum carry a positive charge. This issue has also arisen on previous examinations.

2aai.

Marks	0	1	2	Average
%	33	25	43	1.1

One mark was awarded for a description of relative abundances (either of):

- the relative abundances of the  $^{79}Br$  and  $^{81}Br$  isotopes are approximately equal
- the  $^{79}Br$  isotope is slightly more abundant than the  $^{81}Br$  isotope.

One mark for reference to the molecular ion peaks (either of):

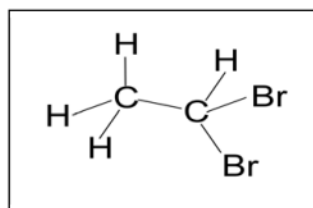
- the peaks at  $m/z = 108$ , i.e.  $[C_2H_5^{79}Br]^+$  and  $m/z = 110$ , i.e.  $[C_2H_5^{81}Br]^+$  are approximately the same height
- the peak at  $m/z = 108$ , i.e.  $[C_2H_5^{79}Br]^+$  is slightly higher than the peak at  $m/z = 110$ , i.e.  $[C_2H_5^{81}Br]^+$ .

Performance on this question suggested that many students struggled to effectively interpret and/or use the information given about the molecular ion peaks. Fundamentally, this was about the different peak heights with the higher peak height at  $m/z=108$  indicating a greater abundance of the lighter molecule – the one with the lighter Br atom. A number of students focused on the peaks for  $^{79}Br$  and  $^{81}Br$  rather than the molecular ion peaks. Expressions such as the peak at  $m/z = 108$  being 60 per cent abundant suggested that the 'relative abundance' scale in the context of mass spectroscopy where the most abundant species is set at relative abundance 100 was not well understood.

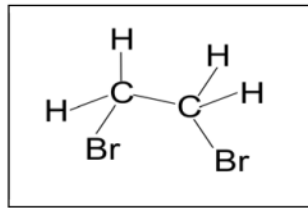
2bi.

Marks	0	1	2	Average
%	4	7	89	1.9

Structure 1



Structure 2



This question was well done.

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2bii.

Marks	0	1	2	3	Average
%	14	6	23	58	2

One mark each was awarded for:

- circling the correct structure in Question 2bi. (Structure 1)
- appropriate reference to the signals on the  $^1\text{H}$  NMR spectrum
- a description of the different H environments in the two compounds.

Possible responses included:

- the NMR spectrum of  $\text{CH}_3\text{CHBr}_2$  shows two sets of peaks/two signals
- the NMR spectrum of  $\text{CH}_3\text{CHBr}_2$  shows a doublet and a quartet
- this is consistent with the structure because there are the two different hydrogen environments – one for the three hydrogen atoms on  $\text{CH}_3$  attached to  $\text{CH}_2\text{Br}$ , and one for the H on  $\text{CHBr}_2$  attached to  $\text{CH}_3$
- this is not consistent with  $\text{CH}_2\text{BrCH}_2\text{Br}$  structure in which all H atoms are in the same environment
- the splitting pattern is consistent with the different hydrogen environments on the  $\text{CH}_3\text{CHBr}_2$  structure, – a doublet for three hydrogen atoms on  $\text{CH}_3$  attached to  $\text{CH}_2\text{Br}$ , and a quartet for H on  $\text{CHBr}_2$  attached to  $\text{CH}_3$ .

Overall performance on this question was strong, aided in part by the fact that it was possible to access full marks without referring to the splitting pattern on the spectrum. Many students who did refer to the signal splitting explained it very well. Students continue to do well on NMR-related questions.

Question 3a.

Marks	0	1	Average
%	33	67	0.7

128 ppm (126–129 ppm was accepted)

Most errors on this question were associated with inaccurate reading of the graph.

3b.

Marks	0	1	Average
%	12	88	0.9

There is no peak at the retention time of caffeine/no peak at 96 seconds.

3ci.

Marks	0	1	Average
%	71	29	0.3

The caffeine peak area is beyond the range of the calibration graph. Extrapolation outside the range of the standard solutions may not be accurate.

Many incorrect responses referred to the caffeine peak on the chromatogram rather than the calibration graph and argued that since the top of the peak was not visible, the peak area could not be measured. However, the peak area of the largest peak (caffeine) for espresso coffee was given in the results summary table.

3cii.

Marks	0	1	Average
%	82	18	0.2

Dilute the espresso coffee sample (either of):

- to bring its caffeine concentration within the range of the calibration curve
- by a factor > 12.

While many responses referred to dilution, the term on its own was not sufficient. Students were expected to either state the purpose of the dilution with respect to using the calibration curve, or suggest a dilution factor that would bring the caffeine concentration within the range of the calibration graph. Responses to such questions should not be superficial.

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## Question 4a.

Marks	0	1	2	3	4	Average
%	24	20	21	22	13	1.8

$$n(\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}) = 4.141 \text{ g} / 245.3 \text{ g mol}^{-1} = 1.688 \times 10^{-2} \text{ mol}$$

$$n(\text{P}_2\text{O}_5) = \frac{1}{2} \times n(\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}) = 8.441 \times 10^{-3} \text{ mol}$$

$$m(\text{P}_2\text{O}_5) = 8.441 \times 10^{-3} \text{ mol} \times 142.0 \text{ g mol}^{-1} = 1.199 \text{ g}$$

$$\% \text{P}_2\text{O}_5 = (1.199 / 3.256) \times 100 = 36.81 \%$$

One mark each was awarded for:

- correctly calculating  $n(\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O})$
- accurately calculating  $n(\text{P}_2\text{O}_5)$
- accurately calculating the  $m(\text{P}_2\text{O}_5)$
- accurately calculating the percentage  $\text{P}_2\text{O}_5$  to four significant figures.

Many students struggled to correctly identify the data relevant to the calculations and attempted to use all data. The key to an efficient response was realising that all the P in 3.256 g of fertiliser ends up in 4.141 g of  $\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O}$ .

Correctly calculating the  $n(\text{P}_2\text{O}_5)$  was particularly challenging, with most students not linking it to  $n(\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O})$ . Since  $n(\text{P}) = n(\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O})$  and  $n(\text{P}_2\text{O}_5) = \frac{1}{2} \times n(\text{P})$  then  $n(\text{P}_2\text{O}_5) = \frac{1}{2} \times n(\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O})$ .

Some students did not gain full marks because their final answer was not given to four significant figures. This was expected because all data that needed to be used in the calculations was given to four significant figures.

## 4b.

Marks	0	1	2	Average
%	72	6	22	0.5

The same, because:

- no P is lost on heating the precipitate
- the mass of the precipitate is divided by the  $M(\text{MgNH}_4\text{PO}_4)$  in calculating the percentage  $\text{P}_2\text{O}_5$ .

The key point in this question was that the precipitate collected had been deliberately heated above 100 °C to completely convert the precipitate to  $\text{MgNH}_4\text{PO}_4$  before weighing. The implication was that it was known that the precipitate collected was now  $\text{MgNH}_4\text{PO}_4$ . So while the mass of precipitate collected will be lower, the calculated  $n(\text{MgNH}_4\text{PO}_4)$  will be the same as the  $n(\text{MgNH}_4\text{PO}_4 \cdot 6\text{H}_2\text{O})$  in 5a. because the mass of precipitate is divided by a lower molar mass. This question was intended to test the more able students.

## Question 5ai.

Marks	0	1	Average
%	34	66	0.7

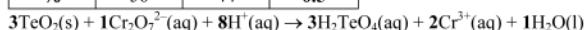
Either of:

- $\text{TeO}_2(\text{s}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2\text{TeO}_4(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{e}^-$
- $\text{TeO}_2(\text{s}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow \text{TeO}_4^{2-}(\text{aq}) + 4\text{H}^+(\text{aq}) + 2\text{e}^-$

Most errors with this equation were associated with the location and number of  $\text{H}^+(\text{aq})$  and  $\text{e}^-$ .

## 5aii.

Marks	0	1	Average
%	56	44	0.5





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Many of the students who had provided the correct answer for 5ai. did not combine the two half-equations effectively. An incorrect coefficient for  $\text{H}_2\text{O}(\text{l})$  was quite common. Further attention should be paid to the combination of half-equations to give the overall redox equation.

### 5b. and 5bii.

Marks	0	1	2	3	4	Average
%	14	8	12	16	50	2.8

Many students were confused about the classifications of dichromate ions – ‘supplied’, ‘in excess’ and ‘reacting with the tellurite’. While most students handled the mathematics of such questions efficiently, logical sequencing proved challenging for some.

### 5bi.

$$\begin{aligned}
 n(\text{Fe}^{2+}) &= 0.0525 \times 19.71 \times 10^{-3} \\
 &= 1.035 \times 10^{-3} \text{ mol } [1.035 \times 10^{-3}] \\
 n(\text{Cr}_2\text{O}_7^{2-}) \text{ in excess (unreacted)} &= n(\text{Fe}^{2+})/6 \\
 &= 1.035 \times 10^{-3}/6 \\
 &= 1.72 \times 10^{-4} \text{ mol}
 \end{aligned}$$

### 5bii.

$$\begin{aligned}
 n(\text{Cr}_2\text{O}_7^{2-}) \text{ supplied} &= 0.03052 \times 50.00 \times 10^{-3} \\
 &= 1.526 \times 10^{-3} \text{ mol} \\
 n(\text{Cr}_2\text{O}_7^{2-}) \text{ reacting} &= 1.526 \times 10^{-3} - 1.72 \times 10^{-4} \\
 &= 1.354 \times 10^{-3} \text{ mol}
 \end{aligned}$$

### 5biii.

Marks	0	1	2	Average
%	35	19	46	1.1

$$\begin{aligned}
 n(\text{TeO}_2) &= 3 \times n(\text{Cr}_2\text{O}_7^{2-}) \text{ reacting} \\
 &= 3 \times 1.354 \times 10^{-3} \\
 &= 4.062 \times 10^{-3} \text{ mol} \\
 m(\text{TeO}_2) &= 4.062 \times 10^{-3} \text{ mol} \times 159.6 \text{ g mol}^{-1} \\
 &= 0.6482 \text{ g ... (units needed to be included)}
 \end{aligned}$$

Students needed to multiply the  $n(\text{Cr}_2\text{O}_7^{2-})$  reacting as calculated in 5bii. by the mole ratio for  $\text{TeO}_2/\text{Cr}_2\text{O}_7^{2-}$  from the equation in 5aii. Some students used an incorrect molar mass, that of  $\text{H}_2\text{TeO}_4$ , which was surprising since  $M(\text{TeO}_2)$  was given at the beginning of the question.

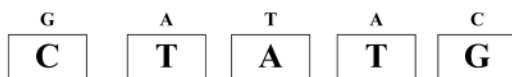
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### Question 6ai.

Marks	0	1	Average
%	6	94	1



### 6aii.

Marks	0	1	Average
%	26	74	0.8

12 hydrogen bonds

Many students were either not aware of or did not apply the fact there are three hydrogen bonds in each G–C link and two hydrogen bonds in each A–T link.

### 6b.

Marks	0	1	2	3	Average
%	8	4	13	76	2.6

All of:

- phosphoric acid/phosphate
- deoxyribose
- adenine.

Students who did not gain full marks on this question often did not correctly name all the reactants. The general groups 'sugar' and 'nitrogen base' were given instead of the specific compounds 'deoxyribose' and 'adenine'.

### Question 7ai.

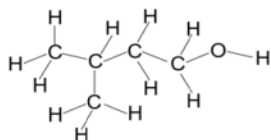
Marks	0	1	Average
%	20	80	0.8

Any of:

- OH<sup>-</sup>
- NaOH
- potassium hydroxide.

### 7aii.

Marks	0	1	Average
%	37	63	0.7



Given that the question asked for a structure rather than the structure showing all bonds, it was not necessary to show all bonds. However, it had to be clear that it is the O end of the OH that is bonded to C, and that there were two CH<sub>3</sub> groups bonded to carbon number 3.

Since the pathway showed that B was an alcohol produced from ClCH<sub>2</sub>CH<sub>2</sub>CH(CH<sub>3</sub>)<sub>2</sub>, and so had to be HOCH<sub>2</sub>CH<sub>2</sub>CH(CH<sub>3</sub>)<sub>2</sub>, it was surprising that many students showed a structure with the incorrect number of carbon atoms.

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7aiii.

Marks	0	1	Average
%	48	52	0.5

3-methylbutan-1-ol or 3-methyl-1-butanol

The performance data for this part of the question indicated that many students who had the correct structure in 7aii. did not provide a correct name for the compound. Many students referred to a dimethyl option rather than identifying the longest chain of C atoms.

7aiv.

Marks	0	1	Average
%	44	56	0.6

Ethanol

Ethanol-1-ol or 1-ethanol was a relatively common response for this question; however, this is not the systematic name. There is no other option for the –OH functional group but to be on C-1, hence the number is not part of the systematic name.

7av.

Marks	0	1	Average
%	49	51	0.5

Any of:

- $\text{H}_2\text{SO}_4$
- sulfuric acid
- $\text{H}_2\text{SO}_4(\text{l})$ .

This question was poorly done. Sulfuric acid is used as a catalyst in ester production. A relatively common error was to give the answer as  $\text{H}_2\text{SO}_4(\text{aq})$  or dilute sulfuric acid.

7avi.

Marks	0	1	Average
%	15	85	0.9

Reaction II

Ethanoic acid is produced from ethanol by oxidation.

7b.

Marks	0	1	2	Average
%	31	42	26	1

Compounds in the mixture are separated according to their boiling temperatures/intermolecular attraction and (any of):

- the most volatile compound (lowest boiling temperature) will be collected first (at the lowest temperature)
- the least volatile compound (highest boiling temperature) will be collected last (at the highest temperature)
- the compounds are collected in order of increasing boiling temperature.

Many responses to this question focused on the fractional distillation of crude oil with emphasis on the fractionating tower and collection of hydrocarbon fractions at different levels in the tower with minimal appropriate, in the context of the question, reference to the role of boiling temperature or intermolecular attraction. Given that the production of esters is the endpoint of chemical pathways covered in this unit, awareness of the technique by which an ester is separated from other compounds present in the reaction mixture is a reasonable expectation. Students should be aware that the key factor that influences boiling temperature is the strength of intermolecular attraction, not molecular mass.

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7c.

Marks	0	1	2	Average
%	46	50	4	0.6

Both of:

- compound B has a distinct O–H (alcohol) absorption band around  $3300\text{ cm}^{-1}$  ( $3200\text{--}3550\text{ cm}^{-1}$ ). This is not present on the spectrum of banana oil
- the IR spectrum of banana oil does not show an O–H (acid) ( $2500\text{--}3300\text{ cm}^{-1}$ ) absorption band.

Students were required to explain how the evidence provided by the spectra supported the claim that ‘complete separation of banana oil from the reaction mixture’ had been achieved. Since the reaction mixture would have contained ethanoic acid and 3-methylbutan-1-ol, it was necessary to indicate how the spectra showed the lack of the acid or the alcohol in the final banana oil product.

While slightly more than half the students were able to argue effectively that there was no alcohol present, few were able to explain how the banana oil spectrum showed that the acid was not present. Many students gave reasons how the banana oil spectrum showed that banana oil was an ester, but that was not relevant to the question.

There was some confusion around the absorption band near  $3100\text{ cm}^{-1}$  on the banana oil spectrum, with a significant number of students suggesting that it was an O–H (acid) band. Students should have been able to recognise the characteristic broad shape of an O–H (acid) band.

Question 8a.

Marks	0	1	Average
%	21	79	0.8

Arg–Pro–Pro–Gly–Phe–Ser–Pro–Phe–Arg

The side groups on the bradykinin molecule section should have enabled students to identify the amino acids from Table 8 of the Data Book.

8b.

Marks	0	1	2	Average
%	18	20	62	1.5

Both of:

- carboxyl or  $\text{COOH}$
- amino,  $\text{NH}_2$  or  $\text{NH}_3^+$ .

It was decided that either the name or the chemical formula of the functional groups was a reasonable response to ‘identify’ the two functional groups.  $\text{NH}_3^+$  was accepted because in 6 M HCl it is fair to assume that the  $\text{NH}_2$  group on the amino acids would be protonated.

Students should be aware that the hydrolysis of proteins converts peptide groups in amino and carboxyl groups.

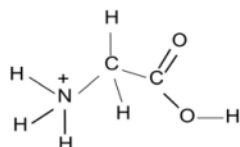
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8c.

Marks	0	1	Average
%	59	41	0.4



A surprising number of students did not show the O–H bond, despite the instruction in the question to show all bonds. Other common errors included missing atoms and either not including the positive charge or showing it as an  $H^+$ .

## Appendix E – 2011 VCE Chemistry Exam

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**Victorian Certificate of Education  
2011**

SUPERVISOR TO ATTACH PROCESSING LABEL HERE

**STUDENT NUMBER**

Letter

Figures

Words


### CHEMISTRY

#### Written examination 1

**Wednesday 15 June 2011**

Reading time: 11.45 am to 12.00 noon (15 minutes)

Writing time: 12.00 noon to 1.30 pm (1 hour 30 minutes)

#### QUESTION AND ANSWER BOOK

##### Structure of book

Section	Number of questions	Number of questions to be answered	Number of marks
A	20	20	20
B	8	8	52
			Total 72

- Students are permitted to bring into the examination room: pens, pencils, highlighters, erasers, sharpeners, rulers and one scientific calculator.
- Students are NOT permitted to bring into the examination room: blank sheets of paper and/or white out liquid/tape.

##### Materials supplied

- Question and answer book of 25 pages.
- A data book.
- Answer sheet for multiple-choice questions.

##### Instructions

- Write your **student number** in the space provided above on this page.
- Check that your **name** and **student number** as printed on your answer sheet for multiple-choice questions are correct, **and** sign your name in the space provided to verify this.
- All written responses must be in English.

##### At the end of the examination

- Place the answer sheet for multiple-choice questions inside the front cover of this book.
- You may keep the data book.

**Students are NOT permitted to bring mobile phones and/or any other unauthorised electronic devices into the examination room.**

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## SECTION A – Multiple-choice questions

## Instructions for Section A

Answer **all** questions in pencil on the answer sheet provided for multiple-choice questions.

Choose the response that is **correct** or that **best answers** the question.

A correct answer scores 1, an incorrect answer scores 0.

Marks will **not** be deducted for incorrect answers.

No marks will be given if more than one answer is completed for any question.

## Question 1

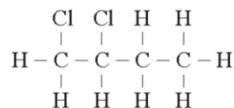
Which one of the following compounds is least soluble in water at room temperature?

- A. ethane
- B. ethanol
- C. ethylamine
- D. ethanoic acid

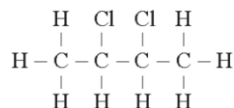
## Question 2

The structure of the product that is formed from the addition reaction between but-2-ene and chlorine,  $\text{Cl}_2$ , is

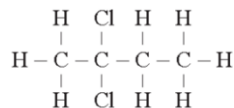
A.



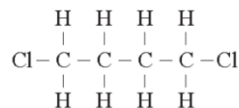
B.



C.



D.

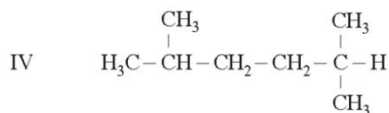
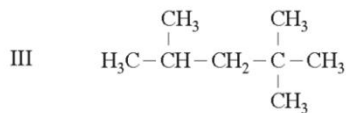
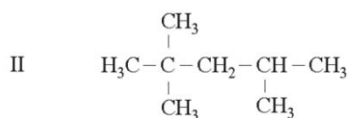
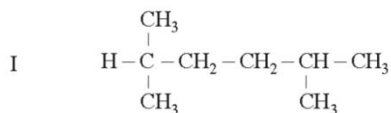


NO WRITING ALLOWED IN THIS AREA

SECTION A – continued

**Question 3**

Consider the following structures.



Which of the above structures is that of 2,2,4-trimethylpentane?

- A. I and III only
- B. I and IV only
- C. II and III only
- D. II and IV only

**Question 4**The compound that is **not** an isomer of 2,2,4-trimethylpentane is

- A. octane.
- B. 3-ethylhexane.
- C. 2,4-dimethylpentane.
- D. 2,4-dimethylhexane.

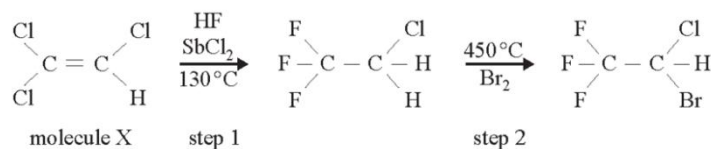
SECTION A – continued  
TURN OVER





**Question 7**

Halothane is a general anaesthetic. The following diagram represents the reaction pathway that produces halothane.



Which one of the following correctly identifies the type of reaction occurring in step 2 and correctly states the systematic name of molecule X?

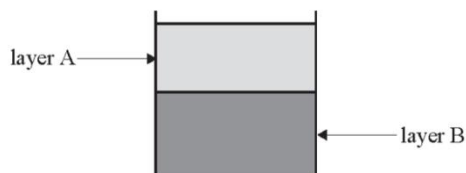
	Type of reaction in step 2	Systematic name of molecule X
A.	substitution	1,2,2-trichloroethane
B.	addition	1,1,2-trichloroethane
C.	substitution	1,1,2-trichloroethene
D.	addition	1,2,2-trichloroethene

SECTION A – continued  
TURN OVER



**Question 9**

Canola oil is completely converted to biodiesel fuel. One of the components of this biodiesel is ethyl stearate. Once cooled, the product mixture of the conversion of canola oil to biodiesel separates into two layers. The top layer, layer A, in the diagram, is the biodiesel fuel.



The following chemicals are involved in the production of biodiesel.

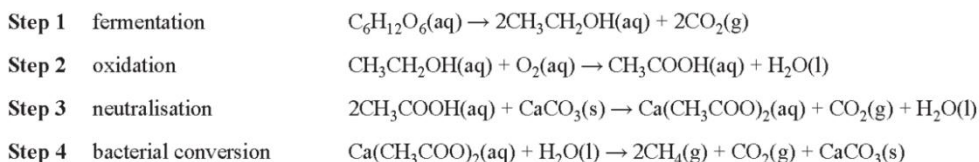
- I glycerol
- II potassium hydroxide
- III ethanol

Which of the above chemicals are found in layer B?

- A. I and II only
- B. I and III only
- C. II and III only
- D. I, II and III

**Question 10**

Biogas can be generated as a by-product of many farming activities. Waste waters often contain sugars, such as glucose, which can be converted to methane. A simplified reaction sequence is given below.



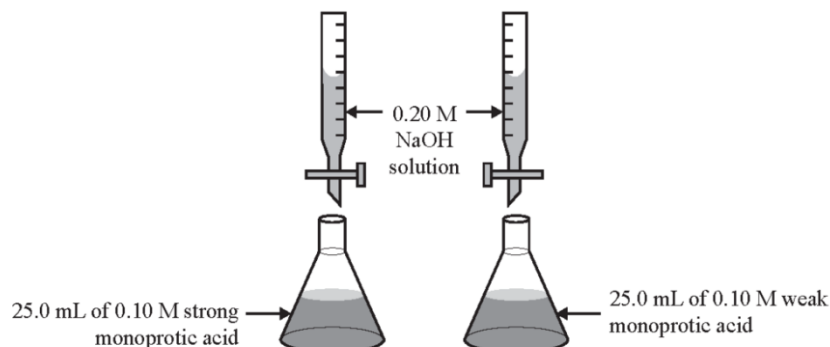
The ratio of the volume of methane produced to volume of carbon dioxide produced in the overall process is

- A. 1:1
- B. 1:2
- C. 2:1
- D. 2:3

SECTION A – continued  
TURN OVER

**Question 11**

Two titrations were performed as shown below.



Which one of the following statements is true?

- A. The weak acid will require a greater volume of NaOH solution than the strong acid to reach the equivalence point.
- B. The weak acid will require a smaller volume of NaOH solution than the strong acid to reach the equivalence point.
- C. The weak acid will require the same amount of NaOH solution as the strong acid to reach the equivalence point.
- D. The equivalence point in a titration of a weak monoprotic acid with NaOH solution cannot be determined.

**Question 12**

To each of three samples of a solution, a different acid-base indicator is added. The following colours are observed.

Indicator	Colour
thymol blue	yellow
methyl red	yellow
phenolphthalein	colourless

The pH of the solution is between

- A. pH = 2.8 and pH = 4.2
- B. pH = 4.2 and pH = 6.3
- C. pH = 6.3 and pH = 8.3
- D. pH = 8.3 and pH = 10.0

NO WRITING ALLOWED IN THIS AREA

SECTION A – continued

**Question 13**

In an experiment, 172.1 g of gypsum,  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ , ( $M = 172.1 \text{ g mol}^{-1}$ ), was heated to constant mass in a large crucible. The loss in mass of the crucible and contents was 27.0 g.

The reaction that occurred when the gypsum was heated was

- A.  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}(\text{s}) \rightarrow \text{CaSO}_4(\text{s}) + 2\text{H}_2\text{O}(\text{g})$   
B.  $2\text{CaSO}_4 \cdot 2\text{H}_2\text{O}(\text{s}) \rightarrow 2\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}(\text{s}) + 3\text{H}_2\text{O}(\text{g})$   
C.  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}(\text{s}) \rightarrow \text{CaSO}_4 \cdot \text{H}_2\text{O}(\text{s}) + \text{H}_2\text{O}(\text{g})$   
D.  $2\text{CaSO}_4 \cdot 2\text{H}_2\text{O}(\text{s}) \rightarrow 2\text{CaSO}_4 \cdot \frac{3}{2}\text{H}_2\text{O}(\text{s}) + \text{H}_2\text{O}(\text{g})$

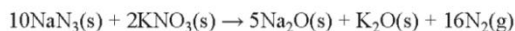
**Question 14**

An analysis is carried out on a sample of unknown gas. The density of the gas is 2.86 grams per litre at STP. The molecular formula of the gas is

- A.  $\text{HCl}$   
B.  $\text{Cl}_2$   
C.  $\text{NO}_2$   
D.  $\text{SO}_2$

**Question 15**

Airbags are an important safety feature of today's cars. The airbag contains a mixture of solid sodium azide,  $\text{NaN}_3$ , and potassium nitrate,  $\text{KNO}_3$ . In the event of an accident, trip sensors send an electric signal to an igniter. The heat generated causes the reactants to decompose completely according to the following equation.



A particular car's airbag was found to inflate to a volume of 62.0 L at a pressure of 100 kPa when the temperature reached  $36.6^\circ\text{C}$ . The molar mass of  $\text{NaN}_3$  is  $65.0 \text{ g mol}^{-1}$ .

What was the mass of sodium azide contained in the car's airbag?

- A. 97.9 g  
B. 156.6 g  
C. 250.6 g  
D. 828.1 g

SECTION A – continued  
TURN OVER

**Question 16**

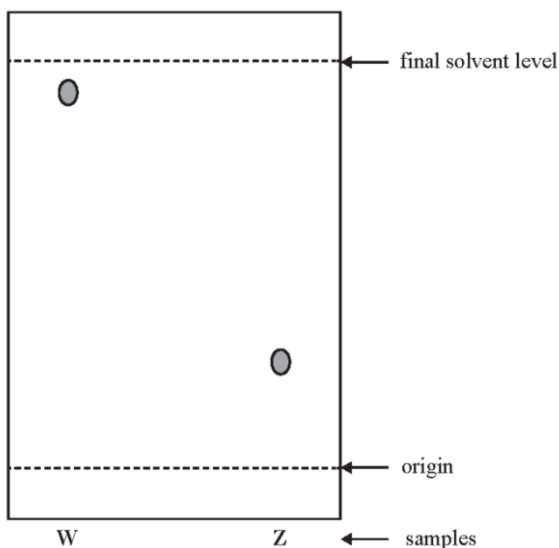
A starch molecule contains 500 glucose units.

If the molar mass of glucose is  $180 \text{ g mol}^{-1}$ , then the molar mass of the starch molecule is

- A.  $8982 \text{ g mol}^{-1}$
- B.  $81018 \text{ g mol}^{-1}$
- C.  $90000 \text{ g mol}^{-1}$
- D.  $98982 \text{ g mol}^{-1}$

**Question 17**

Two different food dye samples, W and Z, were compared using thin layer chromatography as shown below.



- A. Z is more strongly adsorbed than W and has a lower  $R_f$  value.
- B. Z is more strongly adsorbed than W and has a higher  $R_f$  value.
- C. W is more strongly adsorbed than Z and has a lower  $R_f$  value.
- D. W is more strongly adsorbed than Z and has a higher  $R_f$  value.

**Question 18**

The IR wavenumber for bond stretching in a C-O bond ( $1000 - 1300 \text{ cm}^{-1}$ ) is lower than for a C-H bond ( $2850 - 3300 \text{ cm}^{-1}$ ).

Which one of the following statements best explains this fact?

- A. Oxygen atoms are more electronegative than hydrogen atoms.
- B. Oxygen atoms have a greater atomic mass than hydrogen atoms.
- C. Oxygen atoms have a greater atomic radius than hydrogen atoms.
- D. Oxygen atoms have a higher nuclear charge than hydrogen atoms.

NO WRITING ALLOWED IN THIS AREA

SECTION A – continued

**Question 19**

Petrol is a mixture of hydrocarbon molecules varying in size from six to ten carbon atoms. Forensic investigators suspect that traces of a substance found at a suspicious fire could be petrol that was used to start the fire.

Which one of the following techniques could best be used to identify the substance?

- A. NMR spectroscopy
- B. UV-visible spectroscopy
- C. atomic absorption spectroscopy
- D. gas chromatography followed by mass spectroscopy

**Question 20**

The amount of copper in a solution of copper (II) sulfate can be determined using atomic absorption spectroscopy.

When a blue copper (II) sulfate solution is introduced into an atomic absorption spectrometer, a green flame is observed. Consider the following statements.

- I A copper (II) sulfate solution appears blue because it absorbs red light.
- II The metal species undergoes oxidation in the flame.
- III The flame is green due to electron transitions from a higher energy state to a lower energy state.

Which of the above statements are true?

- A. I only
- B. I and III only
- C. II and III only
- D. I, II and III

END OF SECTION A  
TURN OVER





**Victorian Certificate of Education  
2011**

**CHEMISTRY**  
**Written examination**

**Wednesday 15 June 2011**

Reading time: 11.45 am to 12.00 noon (15 minutes)

Writing time: 12.00 noon to 1.30 pm (1 hour 30 minutes)

**DATA BOOK**

**Directions to students**

- A question and answer book is provided with this data book.

Students are NOT permitted to bring mobile phones and/or any other unauthorised electronic devices into the examination room.

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1		atomic number										79		symbol of element										2																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			
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**2. The electrochemical series**

	$E^\circ$ in volt
$\text{F}_2(\text{g}) + 2\text{e}^- \rightleftharpoons 2\text{F}^-(\text{aq})$	+2.87
$\text{H}_2\text{O}_2(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons 2\text{H}_2\text{O}(\text{l})$	+1.77
$\text{Au}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Au}(\text{s})$	+1.68
$\text{Cl}_2(\text{g}) + 2\text{e}^- \rightleftharpoons 2\text{Cl}^-(\text{aq})$	+1.36
$\text{O}_2(\text{g}) + 4\text{H}^+(\text{aq}) + 4\text{e}^- \rightleftharpoons 2\text{H}_2\text{O}(\text{l})$	+1.23
$\text{Br}_2(\text{l}) + 2\text{e}^- \rightleftharpoons 2\text{Br}^-(\text{aq})$	+1.09
$\text{Ag}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Ag}(\text{s})$	+0.80
$\text{Fe}^{3+}(\text{aq}) + \text{e}^- \rightleftharpoons \text{Fe}^{2+}(\text{aq})$	+0.77
$\text{O}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2\text{O}_2(\text{aq})$	+0.68
$\text{I}_2(\text{s}) + 2\text{e}^- \rightleftharpoons 2\text{I}^-(\text{aq})$	+0.54
$\text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) + 4\text{e}^- \rightleftharpoons 4\text{OH}^-(\text{aq})$	+0.40
$\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Cu}(\text{s})$	+0.34
$\text{Sn}^{4+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Sn}^{2+}(\text{aq})$	+0.15
$\text{S}(\text{s}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2\text{S}(\text{g})$	+0.14
$2\text{H}^+(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{H}_2(\text{g})$	0.00
$\text{Pb}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Pb}(\text{s})$	-0.13
$\text{Sn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Sn}(\text{s})$	-0.14
$\text{Ni}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Ni}(\text{s})$	-0.23
$\text{Co}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Co}(\text{s})$	-0.28
$\text{Fe}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Fe}(\text{s})$	-0.44
$\text{Zn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Zn}(\text{s})$	-0.76
$2\text{H}_2\text{O}(\text{l}) + 2\text{e}^- \rightleftharpoons \text{H}_2(\text{g}) + 2\text{OH}^-(\text{aq})$	-0.83
$\text{Mn}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Mn}(\text{s})$	-1.03
$\text{Al}^{3+}(\text{aq}) + 3\text{e}^- \rightleftharpoons \text{Al}(\text{s})$	-1.67
$\text{Mg}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Mg}(\text{s})$	-2.34
$\text{Na}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Na}(\text{s})$	-2.71
$\text{Ca}^{2+}(\text{aq}) + 2\text{e}^- \rightleftharpoons \text{Ca}(\text{s})$	-2.87
$\text{K}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{K}(\text{s})$	-2.93
$\text{Li}^+(\text{aq}) + \text{e}^- \rightleftharpoons \text{Li}(\text{s})$	-3.02

### 3. Physical constants

Avogadro's constant ( $N_A$ ) =  $6.02 \times 10^{23} \text{ mol}^{-1}$

Charge on one electron =  $-1.60 \times 10^{-19} \text{ C}$

Faraday constant ( $F$ ) =  $96\,500 \text{ C mol}^{-1}$

Gas constant ( $R$ ) =  $8.31 \text{ J K}^{-1} \text{ mol}^{-1}$

Ionic product for water ( $K_w$ ) =  $1.00 \times 10^{-14} \text{ mol}^2 \text{ L}^{-2}$  at 298 K  
(Self ionisation constant)

Molar volume ( $V_m$ ) of an ideal gas at 273 K, 101.3 kPa (STP) =  $22.4 \text{ L mol}^{-1}$

Molar volume ( $V_m$ ) of an ideal gas at 298 K, 101.3 kPa (SLC) =  $24.5 \text{ L mol}^{-1}$

Specific heat capacity ( $c$ ) of water =  $4.18 \text{ J g}^{-1} \text{ K}^{-1}$

Density ( $d$ ) of water at  $25^\circ\text{C}$  =  $1.00 \text{ g mL}^{-1}$

1 atm = 101.3 kPa = 760 mm Hg

$0^\circ\text{C}$  = 273 K

### 4. SI prefixes, their symbols and values

SI prefix	Symbol	Value
giga	G	$10^9$
mega	M	$10^6$
kilo	k	$10^3$
deci	d	$10^{-1}$
centi	c	$10^{-2}$
milli	m	$10^{-3}$
micro	$\mu$	$10^{-6}$
nano	n	$10^{-9}$
pico	p	$10^{-12}$

### 5. $^1\text{H}$ NMR data

Typical proton shift values relative to TMS = 0

These can differ slightly in different solvents. Where more than one proton environment is shown in the formula, the shift refers to the ones in bold letters.

Type of proton	Chemical shift (ppm)
$\text{R}-\text{CH}_3$	0.9
$\text{R}-\text{CH}_2-\text{R}$	1.3
$\text{RCH}=\text{CH}-\text{CH}_3$	1.7
$\text{R}_3-\text{CH}$	2.0
$\text{CH}_3-\overset{\text{O}}{\underset{\text{OR}}{\text{C}}}$ or $\text{CH}_3-\overset{\text{O}}{\underset{\text{NHR}}{\text{C}}}$	2.0

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Type of proton	Chemical shift (ppm)
$\begin{array}{c} \text{R} \quad \text{CH}_3 \\ \diagdown \quad / \\ \text{C} \\    \\ \text{O} \end{array}$	2.1
R-CH <sub>2</sub> -X (X = F, Cl, Br or I)	3-4
R-CH <sub>2</sub> -OH	3.6
$\begin{array}{c} \text{O} \\ // \\ \text{R}-\text{C} \\   \\ \text{NHCH}_2\text{R} \end{array}$	3.2
R-O-CH <sub>3</sub> or R-O-CH <sub>2</sub> R	3.3
$\begin{array}{c} \text{O} \\    \\ \text{C}_6\text{H}_5-\text{O}-\text{C}-\text{CH}_3 \end{array}$	2.3
$\begin{array}{c} \text{O} \\ // \\ \text{R}-\text{C} \\   \\ \text{OCH}_2\text{R} \end{array}$	4.1
R-O-H	1-6 (varies considerably under different conditions)
R-NH <sub>2</sub>	1-5
RHC=CH <sub>2</sub>	4.6-6.0
$\begin{array}{c} \text{C}_6\text{H}_5-\text{OH} \end{array}$	7.0
$\begin{array}{c} \text{C}_6\text{H}_5-\text{H} \end{array}$	7.3
$\begin{array}{c} \text{O} \\ // \\ \text{R}-\text{C} \\   \\ \text{NHCH}_2\text{R} \end{array}$	8.1
$\begin{array}{c} \text{O} \\ // \\ \text{R}-\text{C} \\   \\ \text{H} \end{array}$	9-10
$\begin{array}{c} \text{O} \\ // \\ \text{R}-\text{C} \\   \\ \text{O}-\text{H} \end{array}$	11.5

**6.  $^{13}\text{C}$  NMR data**

Type of carbon	Chemical shift (ppm)
$\text{R}-\text{CH}_3$	8–25
$\text{R}-\text{CH}_2-\text{R}$	20–45
$\text{R}_3-\text{CH}$	40–60
$\text{R}_4-\text{C}$	36–45
$\text{R}-\text{CH}_2-\text{X}$	15–80
$\text{R}_3\text{C}-\text{NH}_2$	35–70
$\text{R}-\text{CH}_2-\text{OH}$	50–90
$\text{RC}\equiv\text{CR}$	75–95
$\text{R}_2\text{C}=\text{CR}_2$	110–150
$\text{RCOOH}$	160–185

**7. Infrared absorption data**

Characteristic range for infrared absorption

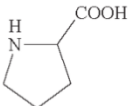
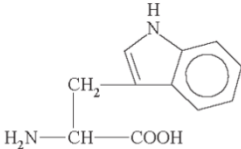
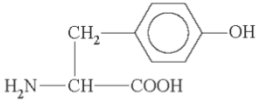
Bond	Wave number ( $\text{cm}^{-1}$ )
$\text{C}-\text{Cl}$	700–800
$\text{C}-\text{C}$	750–1100
$\text{C}-\text{O}$	1000–1300
$\text{C}=\text{C}$	1610–1680
$\text{C}=\text{O}$	1670–1750
$\text{O}-\text{H}$ (acids)	2500–3300
$\text{C}-\text{H}$	2850–3300
$\text{O}-\text{H}$ (alcohols)	3200–3550
$\text{N}-\text{H}$ (primary amines)	3350–3500

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**8. 2-amino acids ( $\alpha$ -amino acids)**

Name	Symbol	Structure
alanine	Ala	$\begin{array}{c} \text{CH}_3 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
arginine	Arg	$\begin{array}{c} \text{CH}_2-\text{CH}_2-\text{CH}_2-\text{NH}-\text{C}(=\text{NH})-\text{NH}_2 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
asparagine	Asn	$\begin{array}{c} \text{O} \\    \\ \text{CH}_2-\text{C}-\text{NH}_2 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
aspartic acid	Asp	$\begin{array}{c} \text{CH}_2-\text{COOH} \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
cysteine	Cys	$\begin{array}{c} \text{CH}_2-\text{SH} \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
glutamine	Gln	$\begin{array}{c} \text{O} \\    \\ \text{CH}_2-\text{CH}_2-\text{C}-\text{NH}_2 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
glutamic acid	Glu	$\begin{array}{c} \text{CH}_2-\text{CH}_2-\text{COOH} \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
glycine	Gly	$\text{H}_2\text{N}-\text{CH}_2-\text{COOH}$
histidine	His	$\begin{array}{c} \text{CH}_2-\text{Imidazole} \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$
isoleucine	Ile	$\begin{array}{c} \text{CH}_3-\text{CH}-\text{CH}_2-\text{CH}_3 \\   \\ \text{H}_2\text{N}-\text{CH}-\text{COOH} \end{array}$



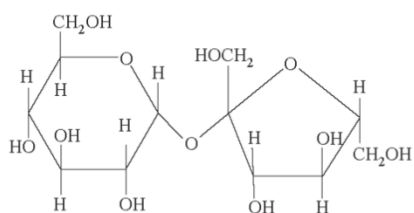
Name	Symbol	Structure
leucine	Leu	$  \begin{array}{c}  \text{CH}_3 - \text{CH} - \text{CH}_3 \\    \\  \text{CH}_2 \\    \\  \text{H}_2\text{N} - \text{CH} - \text{COOH}  \end{array}  $
lysine	Lys	$  \begin{array}{c}  \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{NH}_2 \\    \\  \text{H}_2\text{N} - \text{CH} - \text{COOH}  \end{array}  $
methionine	Met	$  \begin{array}{c}  \text{CH}_2 - \text{CH}_2 - \text{S} - \text{CH}_3 \\    \\  \text{H}_2\text{N} - \text{CH} - \text{COOH}  \end{array}  $
phenylalanine	Phe	$  \begin{array}{c}  \text{CH}_2 - \text{C}_6\text{H}_5 \\    \\  \text{H}_2\text{N} - \text{CH} - \text{COOH}  \end{array}  $
proline	Pro	
serine	Ser	$  \begin{array}{c}  \text{CH}_2 - \text{OH} \\    \\  \text{H}_2\text{N} - \text{CH} - \text{COOH}  \end{array}  $
threonine	Thr	$  \begin{array}{c}  \text{CH}_3 - \text{CH} - \text{OH} \\    \\  \text{H}_2\text{N} - \text{CH} - \text{COOH}  \end{array}  $
tryptophan	Trp	
tyrosine	Tyr	
valine	Val	$  \begin{array}{c}  \text{CH}_3 - \text{CH} - \text{CH}_3 \\    \\  \text{H}_2\text{N} - \text{CH} - \text{COOH}  \end{array}  $

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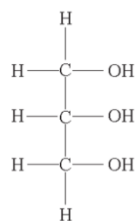
## 9. Formulas of some fatty acids

Name	Formula
Lauric	$C_{11}H_{23}COOH$
Myristic	$C_{13}H_{27}COOH$
Palmitic	$C_{15}H_{31}COOH$
Palmitoleic	$C_{15}H_{29}COOH$
Stearic	$C_{17}H_{35}COOH$
Oleic	$C_{17}H_{33}COOH$
Linoleic	$C_{17}H_{31}COOH$
Linolenic	$C_{17}H_{29}COOH$
Arachidic	$C_{19}H_{39}COOH$
Arachidonic	$C_{19}H_{31}COOH$

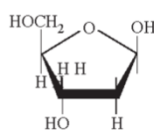
## 10. Structural formulas of some important biomolecules



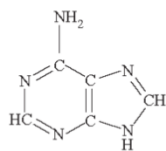
sucrose



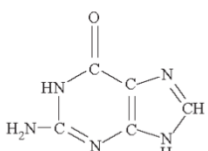
glycerol



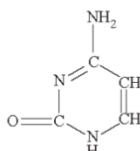
deoxyribose



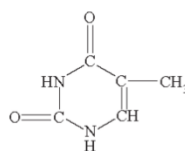
adenine



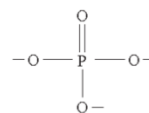
guanine



cytosine



thymine



phosphate

## 11. Acid-base indicators

Name	pH range	Colour change		$K_a$
		Acid	Base	
Thymol blue	1.2–2.8	red	yellow	$2 \times 10^{-2}$
Methyl orange	3.1–4.4	red	yellow	$2 \times 10^{-4}$
Bromophenol blue	3.0–4.6	yellow	blue	$6 \times 10^{-5}$
Methyl red	4.2–6.3	red	yellow	$8 \times 10^{-6}$
Bromothymol blue	6.0–7.6	yellow	blue	$1 \times 10^{-7}$
Phenol red	6.8–8.4	yellow	red	$1 \times 10^{-8}$
Phenolphthalein	8.3–10.0	colourless	red	$5 \times 10^{-10}$

12. Acidity constants,  $K_a$ , of some weak acids at 25°C

Name	Formula	$K_a$
Ammonium ion	$\text{NH}_4^+$	$5.6 \times 10^{-10}$
Benzoic	$\text{C}_6\text{H}_5\text{COOH}$	$6.4 \times 10^{-5}$
Boric	$\text{H}_3\text{BO}_3$	$5.8 \times 10^{-10}$
Ethanoic	$\text{CH}_3\text{COOH}$	$1.7 \times 10^{-5}$
Hydrocyanic	$\text{HCN}$	$6.3 \times 10^{-10}$
Hydrofluoric	$\text{HF}$	$7.6 \times 10^{-4}$
Hypobromous	$\text{HOBr}$	$2.4 \times 10^{-9}$
Hypochlorous	$\text{HOCl}$	$2.9 \times 10^{-8}$
Lactic	$\text{HC}_3\text{H}_5\text{O}_3$	$1.4 \times 10^{-4}$
Methanoic	$\text{HCOOH}$	$1.8 \times 10^{-4}$
Nitrous	$\text{HNO}_2$	$7.2 \times 10^{-4}$
Propanoic	$\text{C}_2\text{H}_5\text{COOH}$	$1.3 \times 10^{-5}$

## 13. Values of molar enthalpy of combustion of some common fuels at 298 K and 101.3 kPa

Substance	Formula	State	$\Delta H_c$ (kJ mol <sup>-1</sup> )
hydrogen	$\text{H}_2$	g	-286
carbon (graphite)	C	s	-394
methane	$\text{CH}_4$	g	-889
ethane	$\text{C}_2\text{H}_6$	g	-1557
propane	$\text{C}_3\text{H}_8$	g	-2217
butane	$\text{C}_4\text{H}_{10}$	g	-2874
pentane	$\text{C}_5\text{H}_{12}$	l	-3509
hexane	$\text{C}_6\text{H}_{14}$	l	-4158
octane	$\text{C}_8\text{H}_{18}$	l	-5464
ethene	$\text{C}_2\text{H}_4$	g	-1409
methanol	$\text{CH}_3\text{OH}$	l	-725
ethanol	$\text{C}_2\text{H}_5\text{OH}$	l	-1364
1-propanol	$\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$	l	-2016
2-propanol	$\text{CH}_3\text{CHOHCH}_3$	l	-2003
glucose	$\text{C}_6\text{H}_{12}\text{O}_6$	s	-2816

END OF DATA BOOK

## Appendix F – VCE Chemistry Study Design: Unit 3 – Area of Study 2

The extended experimental investigation could be student designed and/or planned or teacher directed and would require between three and five hours of practical work. Students could work in pairs or small groups but must present the results individually. Students should complete a Risk Assessment and Risk Management as part of this task. Results could be presented in a variety of formats.

Outcomes	Marks allocated*	Assessment tasks
<b>Outcome 1</b> Evaluate the suitability of techniques and instruments used in chemical analyses.	50	An extended experimental investigation that can be drawn from either area of study 1 or area of study 2.  <b>AND</b> <b>From the area of study NOT used for the extended experimental investigation</b>
<b>Outcome 2</b> Identify and explain the role of functional groups in organic reactions and construct reaction pathways using organic molecules.	25	A written report of one practical activity.  <b>AND</b> One task selected from the following: <ul style="list-style-type: none"> <li>• a response to stimulus material in written, oral or visual format</li> <li>• an analysis of first or second-hand data using structured questions</li> <li>• a report in written, oral, multimedia or visual format related to chemical pathways.</li> </ul>
	25	
<b>Total marks</b>	<b>100</b>	

\*School-assessed coursework for Unit 3 contributes 17 per cent to the study score.

### Mid-year examination

The examination will be set by a panel appointed by the Victorian Curriculum and Assessment Authority.

#### Description

Students will answer a series of questions set by an examination panel.

All key knowledge that underpins the outcomes in Unit 3 and the set of key skills listed on page 12 are examinable.

Outcomes 1 and 2 will contribute approximately equally to the examination.

#### Format

The examination will consist of two sections: Section A multiple-choice items and Section B short-answer items.

#### Conditions

The examination will be completed under the following conditions:

- Duration: one and a half hours.
- Date: mid-year, on a date to be published annually by the Victorian Curriculum and Assessment Authority.

- organic reaction pathways including the production of esters from alkenes, condensation and polymerisation reactions that produce large biomolecules;
- primary, secondary and tertiary structure of proteins and the function of protein catalysts (enzymes);
- biochemical fuels including fermentation of sugars to produce ethanol;
- the structure and bonding of DNA and its applications in forensic analysis;
- use of proteins as markers for disease;
- function of organic molecules in the design and synthesis of medicines including the production of aspirin from salicylic acid.

### ASSESSMENT

The award of satisfactory completion for a unit is based on a decision that the student has demonstrated achievement of the set of outcomes specified for the unit. This decision will be based on the teacher's assessment of the student's overall performance on assessment tasks designated for the unit. The Victorian Curriculum and Assessment Authority publishes an assessment handbook that includes advice on the assessment tasks and performance descriptors for assessment.

The key knowledge listed for each outcome and the set of key skills listed on page 12 should be used as a guide to course design and the development of learning activities. The key knowledge and skills do not constitute a checklist and such an approach is not necessary or desirable for determining the achievement of outcomes. The elements of key knowledge and skills should not be assessed separately.

#### Assessment of levels of achievement

The student's level of achievement in Unit 3 will be determined by school-assessed coursework and a mid-year examination.

##### *Contribution to final assessment*

School-assessed coursework for Unit 3 will contribute 17 per cent to the study score.

The level of achievement for Unit 3 is also assessed by a mid-year examination, which will contribute 33 per cent to the study score.

#### **School-assessed coursework**

Teachers will provide to the Victorian Curriculum and Assessment Authority a score representing an assessment of the student's level of achievement.

The score must be based on the teacher's rating of performance of each student on the tasks set out in the following table and in accordance with an assessment handbook published by the Victorian Curriculum and Assessment Authority. The assessment handbook also includes advice on the assessment tasks and performance descriptors for assessment.

Assessment tasks must be a part of the regular teaching and learning program and must not unduly add to the workload associated with that program. They must be completed mainly in class and within a limited timeframe. Where optional assessment tasks are used, teachers must ensure that they are comparable in scope and demand. Teachers should select a variety of assessment tasks for their program to reflect the key knowledge and skills being assessed and to provide for different learning styles.

School-assessed coursework in Chemistry includes assessment of laboratory/practical work. As a guide, between 10 and 15 hours of class time should be devoted to student laboratory/practical work. Students should maintain records of their work.

**Outcome 1**

On completion of this unit the student should be able to evaluate the suitability of techniques and instruments used in chemical analyses.

To achieve this outcome the student will draw on key knowledge outlined in area of study 1 and key skills listed on page 12.

**Key knowledge**

This knowledge includes

- volumetric analysis: simple and back titrations, acid-base and redox titrations;
- gravimetric analysis;
- calculations including amount of solids, liquids and gases; concentration; volume, pressure and temperature of gases;
- use of oxidation numbers to write redox equations;
- principles and applications of chromatographic techniques and interpretation of qualitative and quantitative data from thin layer chromatography (TLC), high performance liquid chromatography (HPLC) and gas chromatography (GC);
- principles and applications of spectroscopic techniques and interpretation of qualitative and quantitative data from atomic absorption spectroscopy (AAS), infrared spectroscopy (IR), mass spectroscopy, nuclear magnetic resonance spectroscopy (NMR), and visible and ultraviolet spectroscopy (visible-UV);
- matching analytical technique/s to a particular task.

**AREA OF STUDY 2****Organic chemical pathways**

In this area of study students investigate systematic organic chemistry including production of starting materials for particular reaction pathways. Students use molecular models and conduct simple laboratory investigations to observe the properties and reactions of different homologous series and functional groups. Students investigate the use of biochemical fuels. They design reaction pathways to prepare organic compounds from given starting materials.

Students investigate how forensic analysis relies on the use of organic chemicals (including DNA) and the role of organic chemicals (including proteins) in the development of medicines.

**Outcome 2**

On completion of this unit the student should be able to identify and explain the role of functional groups in organic reactions and construct reaction pathways using organic molecules.

To achieve this outcome the student will draw on key knowledge outlined in area of study 2 and key skills listed on page 12.

**Key knowledge**

This knowledge includes

- structure and systematic nomenclature of alkanes, alkenes, amines, chloroalkanes, alkanols and carboxylic acids up to  $C_{10}$ ;
- common reactions of organic compounds: addition reactions of alkenes, substitution reactions of alkanes and primary chloroalkanes, oxidation of primary alkanols, esterification;
- principles of fractional distillation;

- Victorian Curriculum and Assessment Authority examination rules will apply. Details of these rules are published annually in the *VCE and VCAL Administrative Handbook*.
- The examination will be marked by a panel appointed by the Victorian Curriculum and Assessment Authority.

**Contribution to final assessment**

The examination will contribute 33 per cent to the study score.

## Appendix G – Sample Storyboard

### DNA Structure

If possible this animation should include a 3D printing of the same DNA molecule. This way students can follow along with the presentation using their own models. Alternatively a model of an adenine to thymine bond would be worthwhile when discussing the actual bonding.

Take a strand of DNA in ribbon view in VMD. Rotate the DNA once then have it come back to its original position and stop. Have labels appear to show the backbone and several base pairs of nucleotides. From this view, zoom in to show a base pair e.g. adenine bonding to thymine. The rest of the DNA may need to disappear briefly so that the adenine and thymine are better visible. Now change the view to bonds to show exactly how the adenine and thymine bond. Make a note of the two hydrogen bonds here. This is the point in the presentation when the presenter can discuss how the hydrogen bonds shape the DNA. It should also be noted how adenine and thymine only have two hydrogen bonds while cytosine and guanine form three. There are several implications of this including that it is more difficult to break a C-G bond. From here slowly zoom out to show all the bonds in the DNA and how complex it is if we don't have it in ribbon view.

Change the representation back to bonds. Split the DNA into two strands. Once the DNA splits, the presenter should briefly discuss how the DNA codes for proteins. This topic is less of a focus for VCE Chemistry but does allow for an excellent transition into discussing proteins.

### Protein Structure (trypsin)

Now that it has been explained how DNA codes for proteins, a protein can be shown. Trypsin should be used because it is excellent at showing the primary, secondary, and tertiary structures and also is an enzyme. First show the whole molecule with bonds so that students can see how complex trypsin is. Switch to ribbon view and let them see how it is slightly more approachable now. Once in ribbon form the primary structure can be shown by itself. The structure is then discussed by the presenter and replaced with the secondary structure. Now the primary structure is brought back in to show how it compares with the secondary. Then both disappear and are replaced by the tertiary structure. Finally all three representations are shown together. A discussion of how all proteins have a primary, a secondary, *and* a tertiary structure should occur during this animation.



Because trypsin is an enzyme, a discussion of how enzymes work should be included once the structure is finished. The key ideas of the active site should be shown by highlighting it on the trypsin molecule.

Now have trypsin unfold. This part does not need labels. The process of the trypsin unfolding can be shown once so that students get the general idea of what happens. Once folded the three amino acids that form the active site of trypsin get highlighted. The protein is now unfolded so that the students can see how far apart the active sites are when unfolded. Here is where the presenter would explain to the students how in the primary structure the amino acids are far apart but the function of the protein comes from how it gets folded. This should give them the idea that if a protein folds incorrectly then the active sites won't come together properly and work. This will transition into a discussion of denaturing proteins.